UNCLASS

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FC

1. REPORT NUMBER: AFIT/CI/NR/82-23T
2. GOVT ACCESSION NO.: A119062
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Instrumenting an Explosive Test Arena
5. TYPE OF REPORT & PERIOD COVERED: THESIS/~~DISSERTATION~~
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Theodore James Moody
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: AFIT STUDENT AT: The University of Utah
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: IT/NR AFB OH 45433
12. REPORT DATE: June 1982
13. NUMBER OF PAGES: 102
MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASS
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

DISTRIBUTION STATEMENT (of this Report)

PROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-17

30 AUG 1982

LYNN E. WOLAVER
Dean for Research and
Professional Development
AFIT, Wright-Patterson AFB OH

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

ATTACHED

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASS

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

82 09 07 428

AD A119062

DTIC ELECTE SEP 9 1982 D

DTIC FILE COPY

PII Redacted

INSTRUMENTING AN EXPLOSIVE
TEST ARENA

by

Theodore James Moody

An abstract of a thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Kenneth W. Atwood Chairman, Supervisory Committee
Professor of Electrical Engineering

Department of Electrical Engineering
The University of Utah

June 1982

ABSTRACT

Three areas of explosive testing are investigated in this thesis. First, a model of the blast wave is described and a minimum range-bandwidth product is calculated for several percentages of peak overpressure. This product is based on a single-pole, low-pass filter whose cutoff frequency turns out to be a constant divided by the positive impulse duration of the ideal blast wave. The second topic of the thesis covers three ways of removing the noise from the blast waves. One of these methods is to use analog notch filters on the data to remove the frequencies that produce the noise. These notch filters take a considerable amount of time to set-up. Therefore, a digital filter was designed to remove any frequency component whose amplitude is greater than the corresponding frequency component of a comparable ideal blast wave. This works very well, but for those that prefer numerical methods to digital filtering, a least squares program was also developed. This "sliding least squares" computes an estimate of the data based on the fact that any curve can be represented by a series of straight lines. The third section outlines specifications for a digital telemetry system.

This system consists of a Central Control Unit (CCU) and many Field Units (FU). The CCU will control the test from detonation to the final collection of data. Basically it will contain a mini or main frame computer and a transceiver. The FUs (up to 1000) are to be based on a microprocessor and each FU will handle up to eight transducers. Each FU will be battery powered and be capable of operating entirely on its own during the test.

AFIT/CI/NR/82-23T

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to ascertain the value and/or contribution of research accomplished by students or faculty of the Air Force Institute of Technology (ATC). It would be greatly appreciated if you would complete the following questionnaire and return it to:

AFIT/NR
Wright-Patterson AFB OH 45433

RESEARCH TITLE: Instrumenting an Explosive Test Arena

AUTHOR: Theodore James Moody

RESEARCH ASSESSMENT QUESTIONS:

1. Did this research contribute to a current Air Force project?

( ) a. YES ( ) b. NO

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not?

( ) a. YES ( ) b. NO

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency achieved/received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

( ) a. MAN-YEARS ________ ( ) b. $________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3. above), what is your estimate of its significance?

( ) a. HIGHLY SIGNIFICANT ( ) b. SIGNIFICANT ( ) c. SLIGHTLY SIGNIFICANT ( ) d. OF NO SIGNIFICANCE

5. AFIT welcomes any further comments you may have on the above questions, or any additional details concerning the current application, future potential, or other value of this research. Please use the bottom part of this questionnaire for your statement(s).

NAME GRADE POSITION

ORGANIZATION LOCATION

STATEMENT(s):

FOLD DOWN ON OUTSIDE - SEAL WITH TAPE

AFIT/NR
WRIGHT-PATTERSON AFB OH 45433

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE. $300

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 73236 WASHINGTON D.C.

POSTAGE WILL BE PAID BY ADDRESSEE

AFIT/ DAA
Wright-Patterson AFB OH 45433

FOLD IN

22-23T

INSTRUMENTING AN EXPLOSIVE

TEST ARENA

by

Theodore James Moody

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Electrical Engineering

The University of Utah

June 1982

THE UNIVERSITY OF UTAH GRADUATE SCHOOL

SUPERVISORY COMMITTEE APPROVAL

of a thesis submitted by

Theodore James Moody

This thesis has been read by each member of the following supervisory committee and by majority vote has been found to be satisfactory.

21 May 1982 Kenneth W. Atwood

Chairman: Kenneth W. Atwood

21 May 1982 C. K. Rushforth

Craig K. Rushforth

24 May 1982 Clay D. Westlund

Clay D. Westlund

THE UNIVERSITY OF UTAH GRADUATE SCHOOL

FINAL READING APPROVAL

To the Graduate Council of The University of Utah:

I have read the thesis of Theodore James Moody in its final form and have found that (1) its format, citations, and bibliographic style are consistent and acceptable; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the Supervisory Committee and is ready for submission to the Graduate School.

May 24, 1982
Date

Kenneth W. Atwood
Kenneth W. Atwood
Member, Supervisory Committee

Approved for the Major Department

Carl H. Durney
Carl H. Durney
Chairman, Dean

Approved for the Graduate Council

James L. Clayton
James L. Clayton
Dean of The Graduate School

CONTENTS

ABSTRACT..iv

LIST OF FIGURES...vii

PREFACE..viii

INTRODUCTION..1

FREQUENCY RESPONSE..2

1. Model of Blast Wave..2
2. Frequency Requirements.....................................8

FILTERING METHODS..22

1. Sources of Noise..22
2. Spectrum Analysis...26
3. Analog Filters..29
4. Digital Filter..38
5. Numerical Smoothing.......................................45

DIGITAL TELEMETRY SYSTEM.....................................48

1. Central Control Unit......................................48
2. Transceivers..51
3. Field Unit..52

RECOMMENDATIONS..59

Appendices

A. PROGRAM RESPONSE..60

B. PROGRAM SPECTRUM..65

C. PROGRAM SLOPE...71

D. PROGRAM FILTER..74

E. PROGRAM SMOOTH..82

F. PRINTOUT OF RANGE-BANDWIDTH PRODUCTS.......................88

REFERENCES..101

VITA..102

ABSTRACT

Three areas of explosive testing are investigated in this thesis. First a model of the blast wave is described and a minimum range-bandwidth product is calculated for several percentages of peak over-pressure. This product is based on a single-pole, low-pass filter whose cutoff frequency turns out to be a constant divided by the positive impulse duration of the ideal blast wave. The second topic of the thesis covers three ways of removing the noise from the blast waves. One of these methods is to use analog notch filters on the data to remove the frequencies that produce the noise. These notch filters take a considerable amount of time to set-up. Therefore, a digital filter was designed to remove any frequency component whose amplitude is greater than the corresponding frequency component of a comparable ideal blast wave. This works very well, but for those that prefer numerical methods to digital filtering, a least squares program was also developed. This "sliding least squares" computes an estimate of the data based on the fact that any curve can be represented by a series of straight lines. The third section outlines specifications for a digital telemetry system.

This system consists of a Central Control Unit (CCU) and many Field Units (FU). The CCU will control the test from detonation to the final collection of data. Basically it will contain a mini or main frame computer and a transceiver. The FUs (up to 1000) are to be based on a microprocessor and each FU will handle up to eight transducers. Each FU will be battery powered and be capable of operating entirely on its own during the test.

LIST OF FIGURES

1. Development of Explosive Blast Wave................4

2. Ideal Blast Wave....................................4

3. Theoretical Overpressure 7

4. DODESB Bandwidth vs. Peak Overpressure.............9

5. Range-Bandwidth Product vs. Peak Overpressure.....15

6. DODESB Overpressure and Impulse vs. Distance......16

7. Calculated Overpressure and Impulse vs. Distance..17

8. Range-Bandwidth Product vs. Lambda................19

9. Actual Noisy Test Data............................25

10. Power Spectrum of Actual Noisy Test Data..........27

11. Power Spectrum of Ideal Blast Wave................28

12. Adjustable Filter Schematic.......................30

13. Bode Plot of Filter (Notch = 46.5 Hz, Low-Pass = 500 Hz)..............32

14. Bode Plot of Filter (Notch = 39 Hz, Low-Pass = 6300 Hz)...............33

15. Bode Plot of Filter (Notch = 103 Hz, Low-Pass = 10 kHz)...............34

16. Bode Plot of Filter (Notch = 277 Hz, Low-Pass = 6 kHz)................35

17. Data After Analog Filter..........................36

18. Raw Digitized Data................................39

19. Digitized Data Converted To Engineering Units.....41

20. Data After Digital Filtering......................44

21. Data After Numerical Smoothing....................47

PREFACE

This thesis is written with two primary purposes in mind. First and foremost, it is to fulfill the requirements for the Master of Science degree, Department of Electrical Engineering, University of Utah.

Second, the work is intended as a guide for those who must conduct the explosive tests as a part of their regular work. The use of the material in this thesis should make their work easier and more routine.

My sincere thanks to Keaton Turner for his technical advice and to my wife Mary for her patience and understanding.

May 1982 Theodore J. Moody

INTRODUCTION

Three important aspects of explosive testing are described in this thesis. First, the mathematical model of a blast wave is described and a calculation performed to determine the minimum frequency response for the instrumentation system used to record the data. Second, three methods are discussed for filtering the data to remove the unwanted noise added to the signal as a result of the blast. One method is strictly analog, another uses digital filtering techniques, and the third is a numerical method of smoothing the data. The final section of the thesis describes a telemetry system for collecting the data.

FREQUENCY RESPONSE

1. Model of Blast Wave

Two primary factors determine the destructive force of an explosion. The first is the peak magnitude of the blast wave and the second is the duration of the positive phase of the blast wave (the portion of the blast wave whose magnitude is greater than the ambient pressure). A blast wave can be defined as the wave of overpressure which radiates from an explosion and overpressure is the guage pressure, above ambient, in the blast wave.

The primary purpose of the electronics used in this type testing is to measure the peak magnitude and duration of the blast wave. A blast wave is very similar to a sound wave, except it travels at a supersonic velocity, while the sound wave travels at the local speed of sound. In fact, one definition of a blast wave is a compression of air traveling at a velocity greater than the local speed of sound. Once the velocity decreases to the speed of sound, it is no longer a blast wave, but instead, a simple sound wave.

Unlike sound waves, the leading edge of a blast wave (shock front) is discontinuous, much like the waves in the ocean. Even when the source of the wave is not

discontinuous, the shock front will be. One of the properties of air that determines the speed of sound is its density; the more dense the air the greater the propagation velocity of the wave, be it sound or blast wave. Therefore, the blast wave travels fastest in the most dense part of the compressed wave, thus forcing the leading edge of the wave to be discontinuous, as can be seen in Figure 1. As the blast wave passes the transducer it appears as the pressure/time history of Figure 2.

It appears to have an exponential or logarithmic decay and in fact can be modeled by the following equation:

$$P(t) = Pm\ (1-t/to)\ \exp(-at/to)$$

where P(t) is the instantaneous overpressure at time t, Pm is the maximum or peak overpressure observed when t is zero. (to) is the point in time where the overpressure returns to ambient pressure and (exp) is the base of the natural logarithms.

The decay parameter (a), of the above equation, may be regarded as an adjustable factor. It is selected to provide the proper decay rate to match the appropriate values of blast impulse. In other words, it adjusts the slope of the decay between $t = 0$ and $t = to$. For

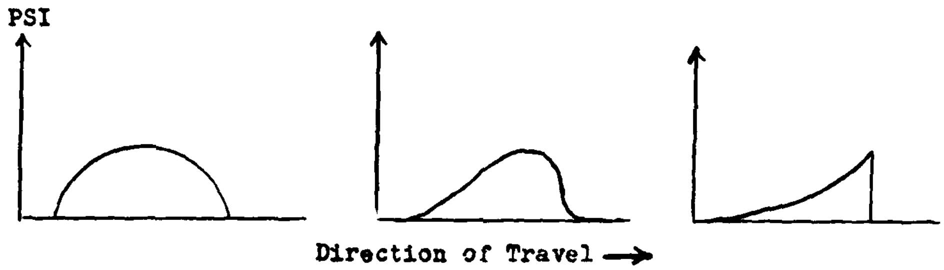


Figure 1. Development of Explosive Blast Wave. The explosion may start as a symmetrical shock front, but as it travels the velocity is greater in the region of higher pressure. Therefore, the wave progresses as shown, becoming discontinuous.

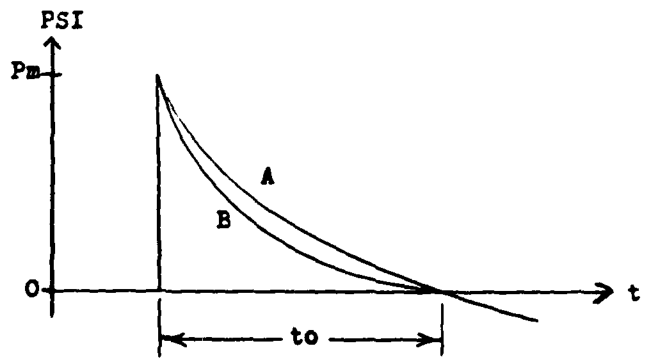


Figure 2. Ideal Blast Wave. The curves A and B show the effect of changing the decay parameter (a) in the Frielander Approximation.

composition B explosives (the type in the AGM-65 missiles), using a = 1.0 gives a very close fit to the experimental data. Therefore, for the remainder of this paper a = 1.0 will be used. This equation[1] is commonly called the Frielander Approximation.

To use this model, one must first know the peak overpressure of the signal and the time for return to ambient pressure. To determine these parameters, one can use the equations developed by the Department of Defense Explosive Safety Board (DODESB) which are based on an extensive amount of experimential data collected over years of testing. These equations[2] are:

for $0.5 < y < 440$:

$$\ln(Pm) = 7.0452041 - 1.6277561(\ln(y)) - 0.27399088*(\ln(y))^2 - 0.065773136*(\ln(y))^3 + 0.0065412563*(\ln(y))^4 + 0.048236359*(\ln(y))^5 - 0.020072553*(\ln(y))^6 + 0.0030190449*(\ln(y))^7 - 0.00015984026*(\ln(y))^8$$

for $40 < y < 1000$:

$$Pm = (226.61762)/y^{1.4065913}$$

$$y = \text{range} / (\text{explosive weight})^{1/3}$$

---

[1]G.F. Kinney, Explosive Shocks in Air, (The MacMillan Company, New York, 1962), pp. 63-87.

[2]L. Giglio-Tos and T.E. Linnenbrink, "Air Blast Pressure Measurement Systems and Techniques," Minutes, 15th Department of Defense Explosive Safety Board Seminar, September 1973, p. 1400.

if $y < 2.048$:

$$\text{Impulse} = \text{range} * \text{antilog}(g)$$

where:

$$g = 2.4177*(\log(y))^2 - 1.5278*(\log(y)) + 1.30103$$

if $y > 2.048$:

$$\text{Impulse} = \text{range} * 42.5733 / (y^{1.829}).$$

Since the impulse is actually the integral of P(t) from t = 0 to t = to, one can analytically solve the integral for (to) with the following result:

$$to = 0.001 * \text{impulse} * 2.718281828 / Pm.$$

The result of these equations can be seen in the theoretical plot of P(t) for a TNT explosive weight of 100 pounds at a range of 25 feet, Figure 3. As the plot shows, P(t) actually has a negative component, which should not be surprising due to conservation of matter (A compression of air followed by a rarefaction of the air).

Since the blast wave is discontinuous at the leading edge, one would expect the Fourier transform to have an infinite spectrum, which is true. However, in the next section it will be shown that with the proper use of filters, one can predict the actual peak

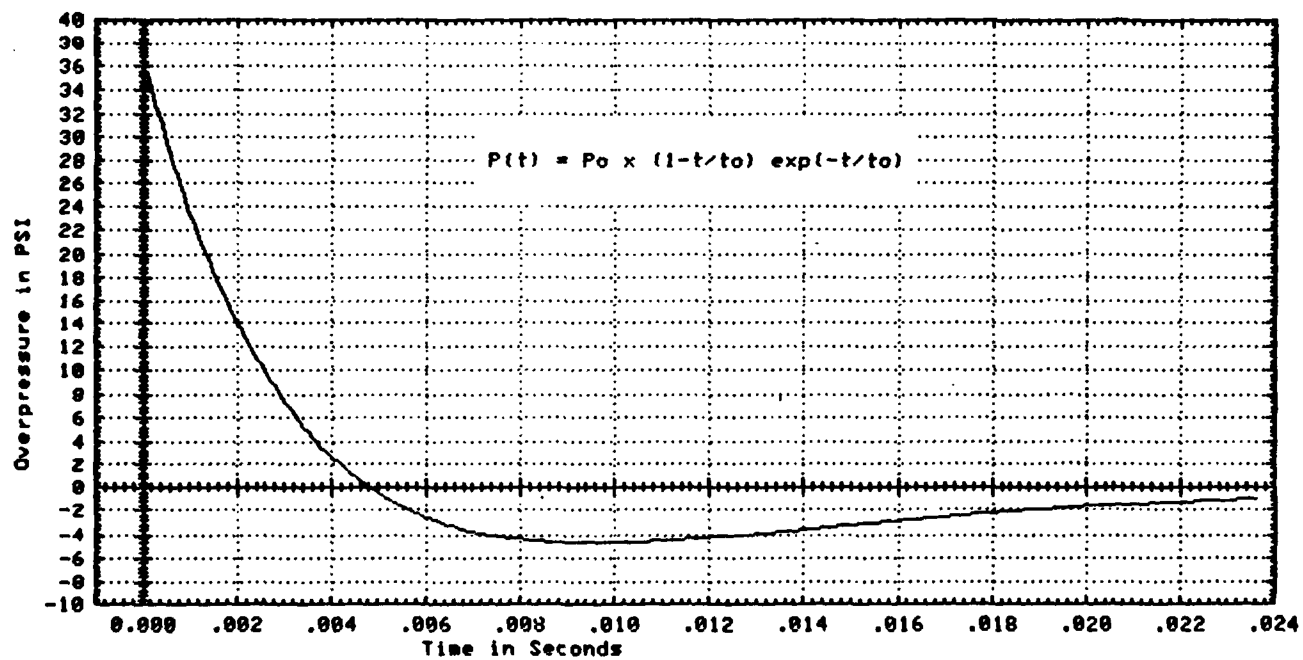


Figure 3. Theoretical Overpressure (100 lbs TNT, Range 25 feet)

amplitude of the blast wave given the filter response and the frequency cutoff of the low-pass filter.

2. Frequency Requirements

When the DODESB wrote their directive[3] for explosive testing, they relied on the work[4] of L. Giglio-Tos and T. E. Linnenbrink for frequency requirements of the data acquisition system. In developing the frequency requirements, Mr. Giglio-Tos and Mr. Linnenbrink used a very simple model for the blast wave:

$$P(t) = Pm * (\exp(-ct))$$

which explains why their curves, Figure 4, do not have a direct dependency on range. This dependency comes only when one takes into account the duration of the positive portion of the blast wave, (to), as described in the previous section. They explain that their curves are based on an explosive weight of one pound and to extrapolate the curves to other explosive weights one should divide the bandwidth required for one pound by the cube root of the actual charge weight. This is an

---

[3]Department of the Air Force Technical Order TO 11A-1-47, Department of Defense Explosive Hazard Classification Procedures, March 1981, para. 6-2.C.

[4]L. Giglio-Tos and T.E. Linnenbrink, "Air Blast Pressure Measurement Systems and Techniques," Minutes, 15th Department of Defense Explosive Safety Board Seminar, September 1973, pp. 1359-1402.

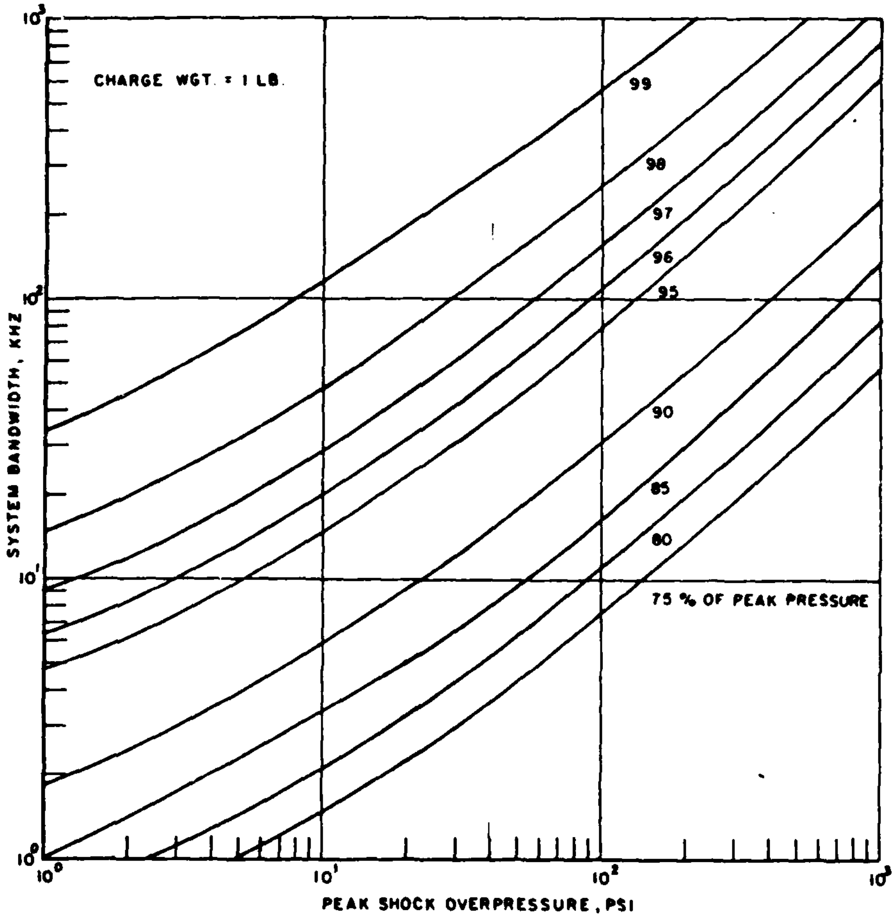


Figure 4. DODESB Bandwidth vs. Peak Overpressure

unproven extension of the scaling law[5] which has been proven by others. However, DODESB recommended a minimum system frequency response[6] of 20 kHz for all tests.

A much more accurate bandwidth requirement can be obtained by starting with the Frielander approximation instead of the simple exponential.

The Laplace transform of this approximation is:

$$\frac{P(s)}{Pm} = \frac{1}{s + 1/to} - \frac{1}{to}\left(\frac{1}{[s + 1/to]^2}\right)$$

where:

$$(s + 1/to) > 0.$$

Assuming the instrumentation system has a transfer function of a simple, single pole, low-pass filter, then:

$$H(s) = a/(s + a). \qquad (2)$$

would be its Laplace transform, where (a) is the cutoff frequency (-3 dB point) in radians per second.

Multiplying equations (1) and (2) in the Laplace domain and transforming the result back to the time domain is the equivalent of convolving the respective time domain equations to produce the output of the instrumentation system, y(t).

---

[5]G.F. Kinney, Explosive Shocks in Air, (The MacMillan Company, New York, 1962), pp. 89-100.

[6]Department of the Air Force Technical Order TO 11A-1-47, Department of Defense Explosive Hazard Classification Procedures, March 1981, para. 6-2.C.

Using this procedure gives:

$$Y(s) = P(s)H(s)$$

Substituting equations (1) and (2) for P(s) and H(s):

$$\frac{Y(s)}{Pm} = \frac{a}{(s + a)\ (s + 1/to)} - \frac{a/to}{(s + a)(s + 1/to)^2}.$$

Expanding these two terms with Partial Fractions yields:

$$\frac{Y(s)}{Pm} = \frac{ato}{ato-1}\left(\frac{1}{s + 1/to} - \frac{1}{s + a}\right)$$

$$- \frac{ato}{(ato-1)^2}\left(\frac{1}{s + a} - \frac{1}{s + 1/to}\right)$$

$$- \frac{a}{ato-1}\left(\frac{1}{s + 1/to}\right)^2,$$

and transforming back to the time domain:

$$\frac{y(t)}{Pm} = \frac{ato}{ato-1}\,[\exp(-t/to) - \exp(-at)]$$

$$- \frac{ato}{(ato-1)^2}\,[\exp(-at) - \exp(-t/to)]$$

$$- \frac{ato}{ato-1}\,[t/to][\exp(-t/to)].$$

Rearranging and combining terms yields the data as would be recorded by the instrumentation system:

$$y(t) = Pm\ \{[ato/(ato-1)][(1-t/to)(\exp(-t/to))-\exp(-at)]$$
$$+ [ato/(ato-1)^2][\exp(-t/to)- \exp(-at)]\}. \qquad (3)$$

As a simple check of this result let (a) approach

infinity in equation (3). This yields the original Frielander approximation, which it should, since letting the low-pass filter have an infinite cutoff frequency is the same as H(s) = 1, or not having a filter at all.

The objective of this mathematical exercise is to determine the cutoff frequency of the filter which will produce a specific percentage of y(t). Therefore, the next logical step should be to take the derivative of y(t) with respect to (t). Then set the derivative equal to zero and solve for (t). This would determine the time (t) that the maximum occures. The next step would be to substitute this value of (t) into equation (3) and solve for the value of (a) that produces the desired percentage. However, equation (3) is transidential and as such cannot be solved by normal means.

ne method that works fairly well is to guess a value for (a) and increment (t) until a maximum is reached. If it is not the desired maximum, then a new value of (a) is tried and the process is repeated until the desired percentage is achieved.

Through trial and error calculations, I found the cutoff frequency in hertz, (a), to have the relation:

$$a = k/to$$

where (k) varies according to the desired percentage of Pm. This variation is shown in the following table.

Percentages and Corresponding Constants

Percentage	k
99	205.435
98	89.290
97	54.1365
96	37.6695
95	28.2816
90	11.1493

The program Response (Appendix A) was an aid in performing this iteration. It asks the operator for a pole multiplier (pmult), a constant equal to twice the value of (k). Then the program selects a value for lambda (range divided by the cube root of the explosive weight) and computes the necessary values of impulse, Pm, and (to).

With (to) computed, the radian value of the cutoff frequency is computed by:

$$a = (pmult)*(pi)/to.$$

Then the time interval between $t = 0$ and $t = to$ is divided into 10 000 increments and equation (3) is tested with each increment starting with $t = 0$ and stopping when a maximum is found.

In the calculation of y(t), Pm = 1.0, therefore, the maximum value of y(t) is actually the percentage of maximum peak overpressure of the ideal blast wave. This value of y(t) along with the corresponding values of bandwidth (in hertz) and lambda are output to files for future reference.

The program then returns to select a new value for lambda and the process starts over again. This loop ends up computing 200 increments of lambda and the corresponding values of y(t) and bandwidth.

The program assumes a value of range equal to one foot. Therefore, the bandwidth that is computed by the program is actually a range-bandwidth product. The range-bandwidth product is plotted in Figure 5 against peak overpressure for 90 and 95 to 99 percent of peak overpressure. Comparing Figures 4 and 5, over the range of 1-1000 psi, a large discrepancy can be seen. This difference is due primarily to the simplistic model that was used to develope the curves of Figure 4.

There appears to be a good correlation between the curve published by DODESB for peak overpressure vs. scaled distance (lambda) and the equations that were derived from this curve. The DODESB curve is shown in Figure 6 (P curve) and the curve plotted from the equations is shown in Figure 7 (P curve).

The equations I developed for the impulse, appear

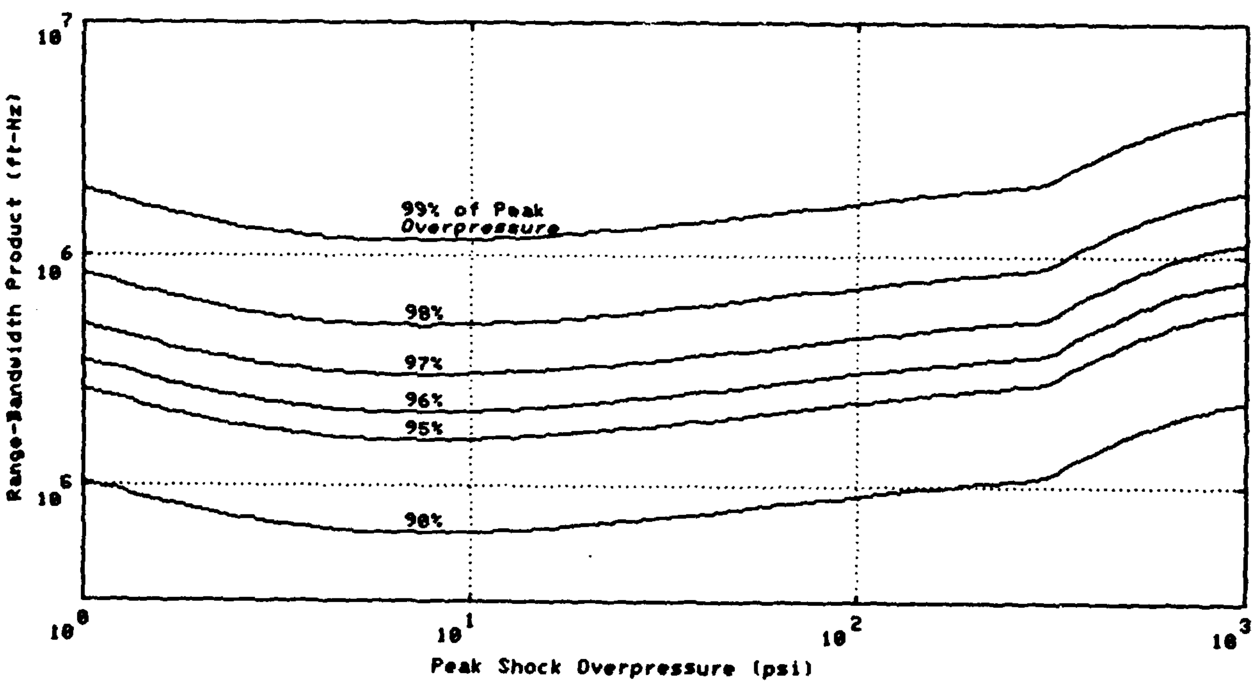


Figure 5. Range-Bandwidth Product *vs.* Peak Overpressure

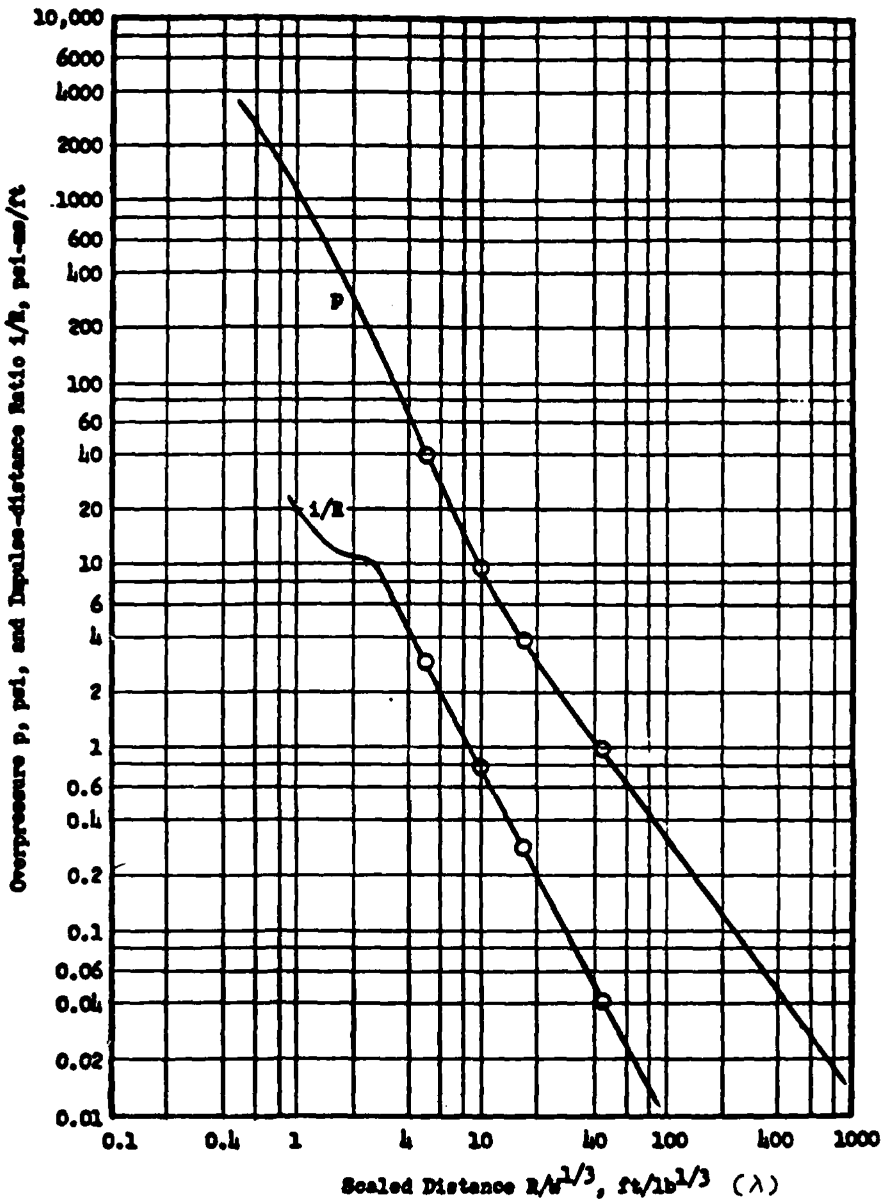


Figure 6. DODESB Overpressure and Impulse vs. Distance From TNT Hemishpere

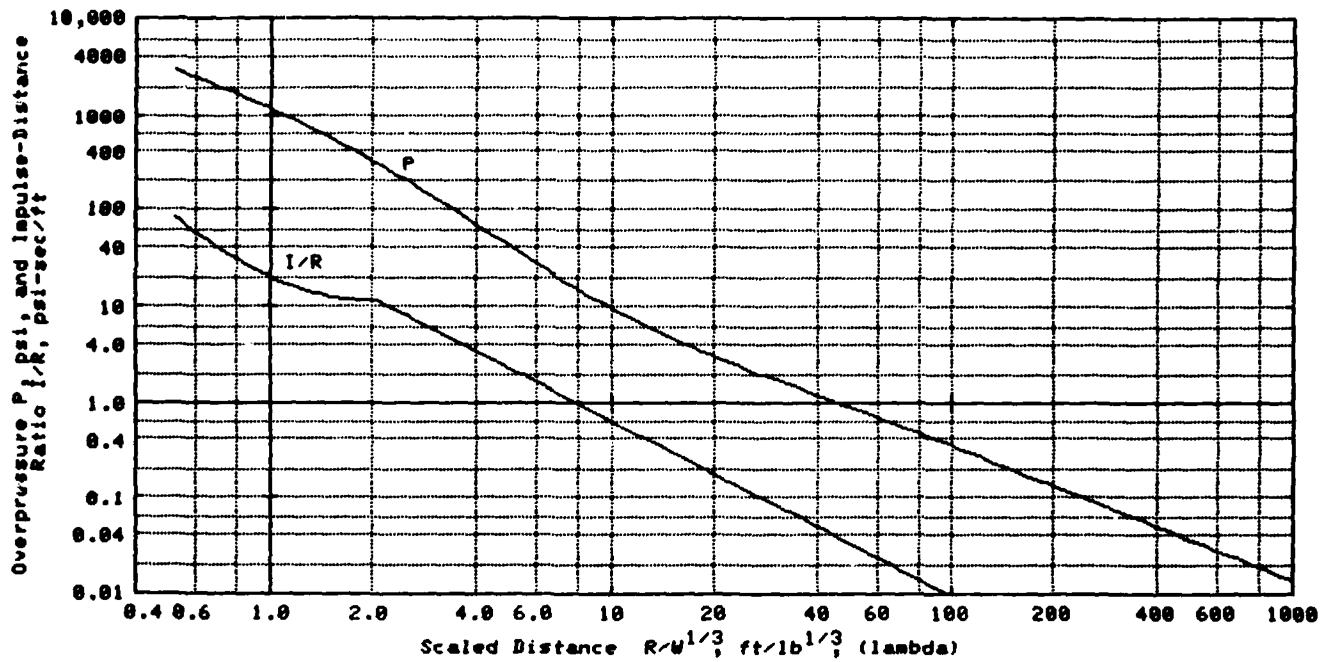


Figure 7. Calculated Overpressure and Impulse vs. Distance From TNT Hemisphere

to match the curve of Figure 6 quite well over the entire interval. These equations were required for use in the computer programs.

The range-bandwidth product is plotted vs. lambda for 90 and 95 to 99 percent of peak overpressure in Figure 8. This plot is possibly more useful to the engineer than Figure 5 because other parameters he has to calculate are also in terms of lambda.

In determining the required bandwidth or frequency response for a particular transducer, one must first estimate lambda, read the range-bandwidth product from Appendix F, and then divide this product by the distance the transducer will be located from the center of the explosion, ground zero. If a single-pole filter is used for each transducer, the actual peak overpressure could be calculated.

As an example, assume that a transducer is to be placed 25 feet from a 100 pound (TNT equivalent) explosion. Lambda would equal 25 divided by the cube root of 100 or:

$$\text{lambda} = 25/4.6416 = 5.3861.$$

Then from Appendix F, for 95 percent, the range-bandwidth product would be 188 440. Dividing this by 25 feet produces a required bandwidth of 7538 Hz.

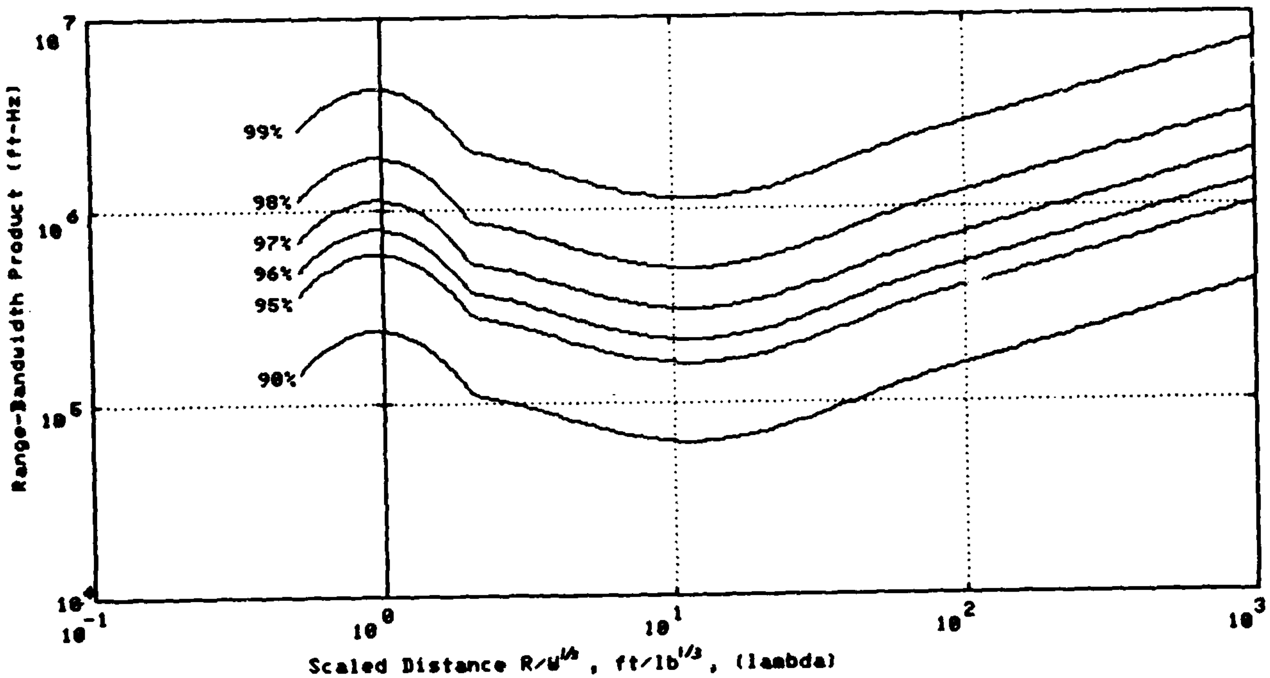


Figure 8. Range-Bandwidth Product vs. Lambda

The filter for this transducer would be set for a cutoff frequency of 7540 Hz.

If after the test, it was found that this transducer measured a peak overpressure of 34 psi, then the actual peak overpressure could be calculated by dividing the 34 psi by 0.95, or:

$$
\begin{aligned}
Pm &= Ymax / \% \\
&= 34 / 0.95 \\
&= 35.8 \text{ psi.}
\end{aligned}
$$

Note also, that for a one pound charge, the instrumentation system with a bandwidth of 20 kHz will record at least 95% of the peak overpressure if the transducer is located eight feet from ground zero and 99% only if located over 200 feet away. Likewise, if the charge is 1000 pounds then the minimum range for the transducer would be 18 feet to assure recording at least 95% of peak overpressure.

The above makes two obvious assumptions, first that the TNT equivalent explosive weight of the charge being tested can be accurately estimated. If this were the case, there would be little need for the test in the first place. However, for lambda in the range of 2-60, the curves of Figure 8 are relatively constant and a poor guess of explosive weight would make less than 1%

change in the amplitude of the recorded peak. For this reason, the transducers should be located in this region, when possible.

The second assumption is that the received signal, y(t), is free of noise and has an ideal shape. This is a very unrealistic assumption and dealing with the noise is a major part of reducing the data to useable information. It is the subject of the following section.

FILTERING METHODS

1. Sources of Noise

There are many types of noise (defined here as unwanted signal) added to the blast wave by the time it is recorded. Among them are the noises commonly encountered by an instrumentation system such as white noise and 1/f noise. These can be dealt with by standard means.

However, there are noises that are peculiar to explosive testing. These noises create a real problem for the engineer trying to produce reliable data for the agency requesting the test.

One of these noises contaminating the blast waves is called Electro-Magnetic Pulses (EMP), caused by the detonation of the explosive. Any time there is an explosion, energy is released at all frequencies from dc to those in the spectrum of light. A certain percentage are in the radio frequency range and are coupled into the instrumentation system through the wiring. Preventing the EMP from being recorded is extremely difficult and expensive. However, the EMP is relatively easy to seperate from the data since it only occurs at the instant of the explosion and the blast wave takes a

finite amount of time, usually several milliseconds, to reach the transducers. Therefore, the EMP noise can be literally erased or ignored. This EMP noise pulse can even be helpful when used as a start time to measure the time of travel of the blast wave between ground zero and the transducer.

Another form of noise is very large spikes with a very short duration. Since the signal from the transducer is zero 99% of the time and only takes a non-zero value during the passage of the blast wave, the average output signal power of the transducer is very small. At the same time noise (white) has an average amplitude that may be as high as 150 millivolts. Mr. Schwartz has shown[1] that the output noise power is not only proportional to the average input amplitude, but also the power is directly proportional to the bandwidth of the system. Therefore, the signal to noise ratio (SNR) for this type of system is going to be inversely proportional to the bandwidth and quite small to start with.

One of the advantages of using an FM recording system is the ability to record very low frequencies accurately. However, below an SNR of about 13 dB the noise "quieting" properties start to deteriorate rapidly

---

[1]M. Schwartz, Information Transmission, Modulation and Noise, 3rd ed., (McGraw-Hill Book Company, New York, 1980), p. 351.

and below 8 dB an AM system actually has better noise characteristics. At even lower values of SNR, the analysis falls apart completely because it is based on a large SNR.

Since the signal is small to begin with, increasing the bandwidth decreases the SNR to the point that the system will see noise that would not be there otherwise. Theoretically the noise could dominate the system.

I recommend the use of filters on each of the transducers with the lowest possible cutoff frequency to reduce this type of noise. Another way to reduce the noise would be to not use the FM system at all, instead one could use an AM system. Even better would be a digital system like the one described in the last section of this thesis.

The most significant problems of noise occur when a blast fragment passes near a transducer. These fragments cause a sonic boom type shock wave to be superimposed on the blast wave. The result is a signal in which one cannot determine the peak of the blast wave nor the positive phase impulse. See Figure 9 for an example.

Analyzing and removing this type of noise is the subject of the following sections.

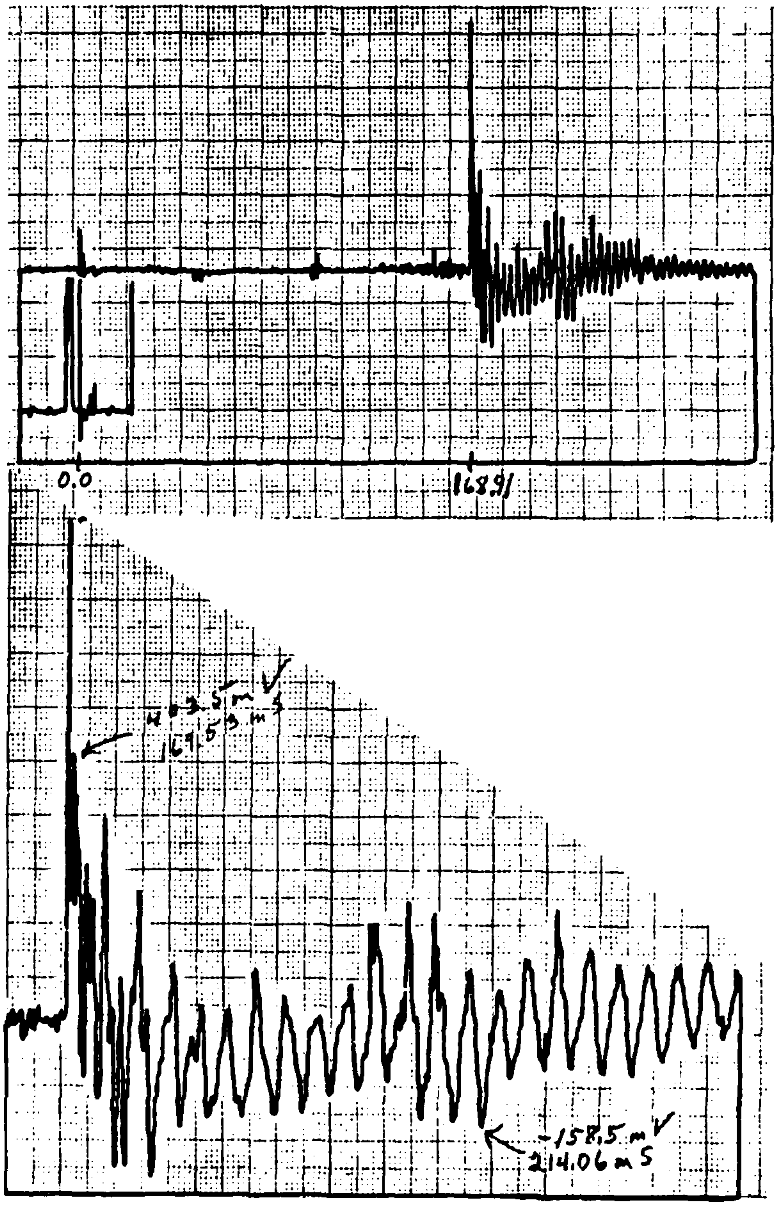


Figure 9. Actual Noisy Test Data (Overpressure vs. Time)

2. Spectrum Analysis

Before attempting to filter the data, I wrote a Fortran program to determine the power spectrum of a signal. This program (Appendix B), Spectrum, reads the signal from a file and computes the magnitude and power spectrum of the Fourier transform. Spectrum then files each in a seperate file for later plotting.

Figure 10 shows the power spectrum of the actual test data in Figure 9, and Figure 11 shows the power spectrum of a comparable ideal blast wave. Comparing the two, we can see roughly what would have to be done to make the actual data have the same shape as the ideal.

Many of the frequencies would have to be reduced and many others should be increased. One cannot totally remove the frequencies that exceed the ideal power spectrum (comb filter), because a certain amplitude of those frequencies is required to make up the ideal wave. Likewise, how much should the frequencies below the ideal be increased? If one makes the power spectrum of the actual data match the ideal exactly, then nothing has been gained. However, if the actual data spectrum could be made to have the same general shape as the ideal with the amplitude proportional to the actual, then the data would appear identical in shape to an ideal blast wave.

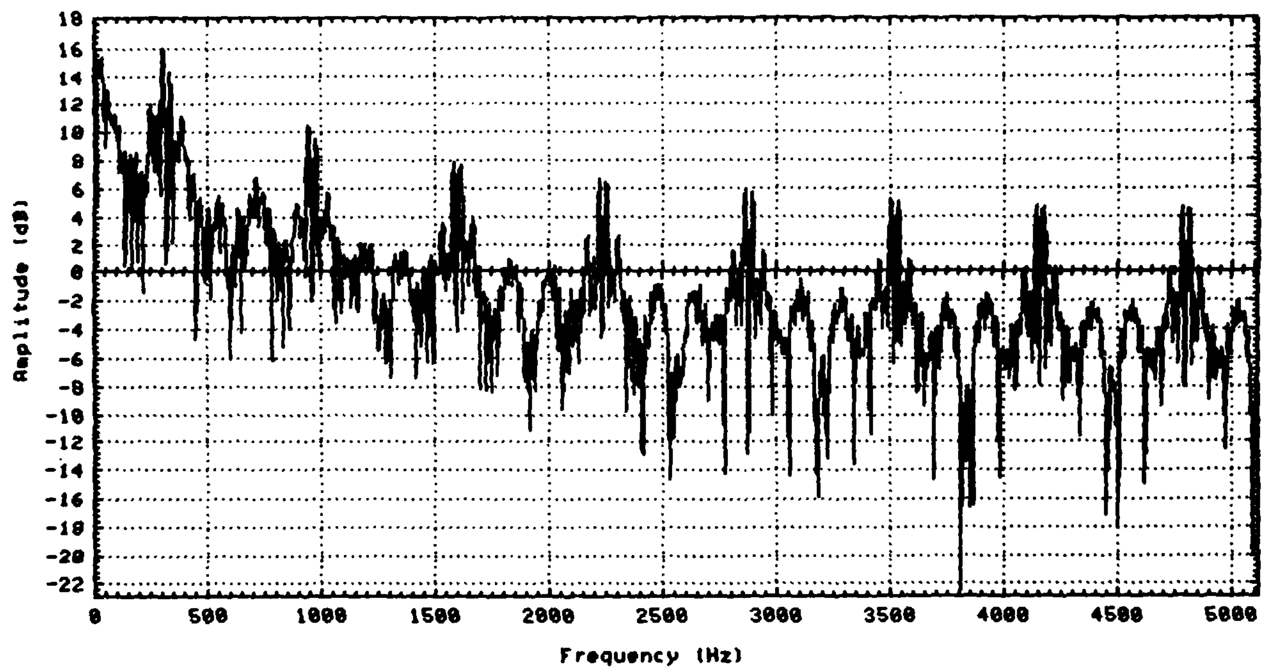


Figure 10. Power Spectrum of Actual Noisy Test Data

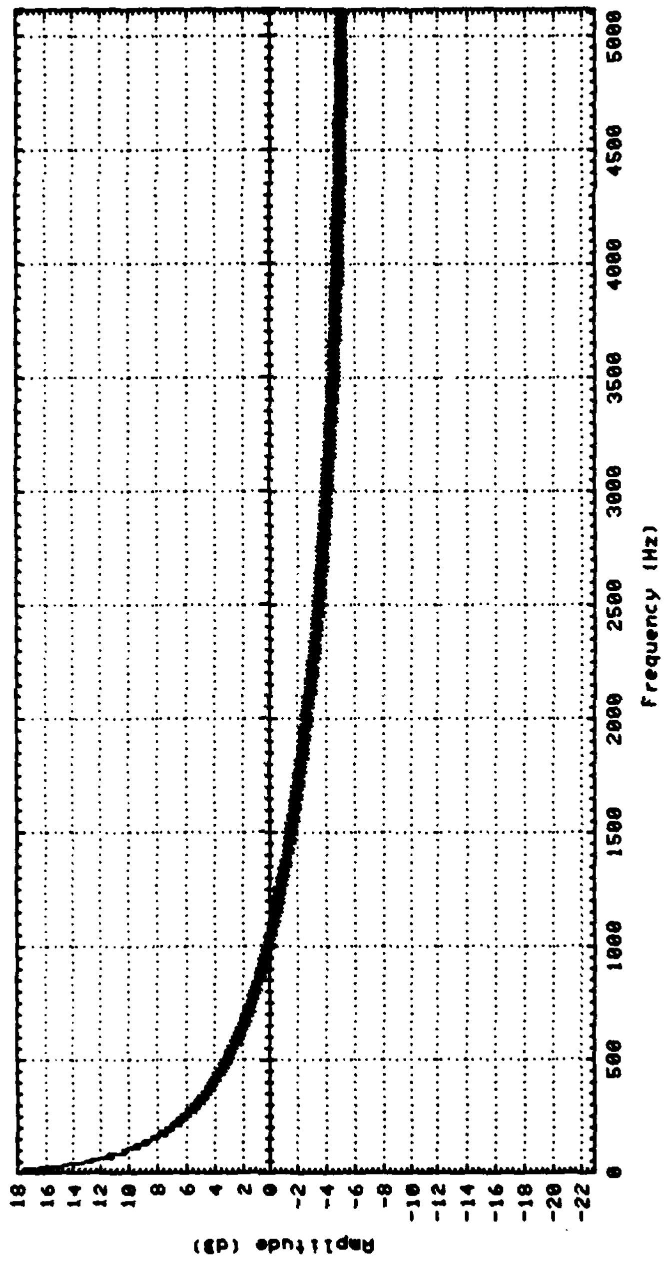


Figure 11. Power Spectrum of Ideal Blast Wave

Each transducer and each test produces a different set of noise frequencies to be removed from the data. Therefore, designing a filter to remove the noise before it is recorded would be very difficult, perhaps an adaptive filter could be used. A simpler method, though, might be to record the noisy data and then try to remove the noise.

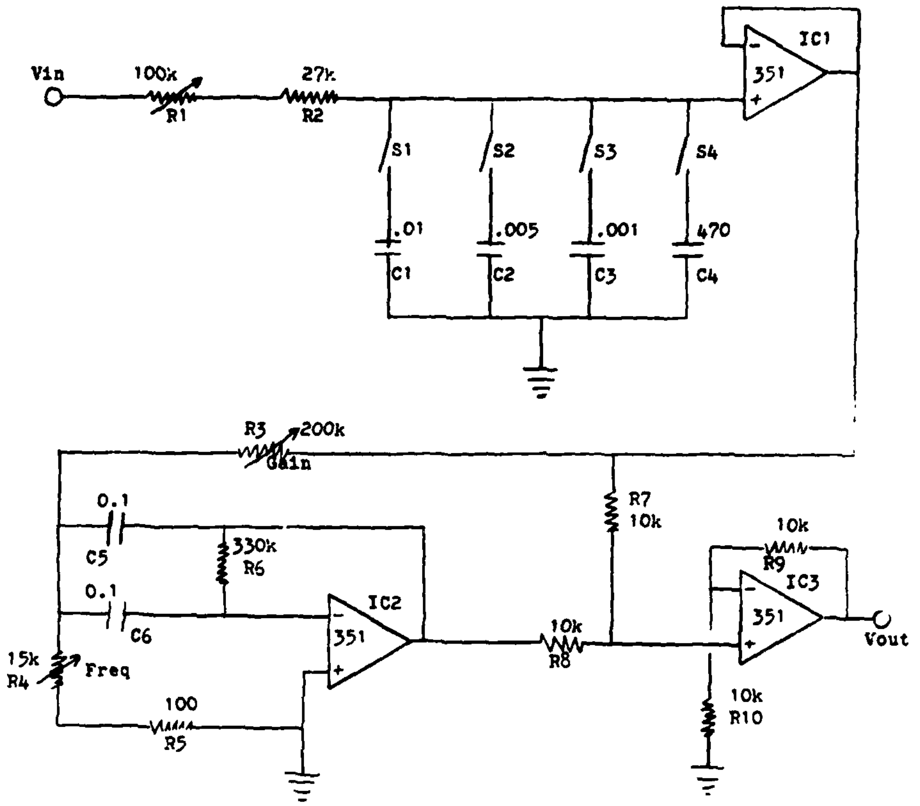
3. Analog Filters

The data I had to work with was stored on analog tape, recorded at 120 inches per second (ips). This tape recorder will play back data at any of several slower speeds. A playback speed of 15 ips was chosen, this speed reduces all frequencies by a factor of eight and increases all times by the same factor of eight.

Figure 12 is the filter circuit I designed to help remove the sonic boom noise from the blast wave. It incorporates a single-pole filter because the data I was working with had not been filtered previously.

The section of the circuit consisting of R1, R2, and C1 through C4 is the low-pass filter and has a variable cutoff frequency of 125 to 10 000 Hz as indicated in the figure. IC1 is a voltage follower to isolate the low- pass filter from the notch filter, which is the remainder of the circuit.

A standard active, band-pass filter has a transfer



SWITCH NO.	Fc (Hz)	R1+R2 (k)
1	125-500	127-32
2	625-1000	51-32
3	1250-5000	127-32
4	6250-10,000	51-32

(Center Frequency of notch is variable over the Range of 25-250 Hz)

Adjustments:
1. Connect sine wave generator to Vin and scope to Vout.
2. Set R4 to maximum resistance.
3. Set sine wave generator to desired low-pass cutoff frequency.
4. Select proper capacitor with switch.
5. Adjust R1 until output is 0.707 times the input.
6. Set sine wave generator to desired notch frequency.
7. Adjust R4 for minimum output.
8. Adjust R3 for desired attenuation.

Figure 12. Adjustable Filter Schematic

function:

$$H(s) = \frac{-(Ho)a(Wo)s}{s^2 + a(Wo)s + (wo)^2}.$$

Note the negative sign. Adding the orignal signal to the output of the band-pass filter makes the circuit a notch filter with the transfer function:

$$H(s) = 1 - \frac{(Ho)a(Wo)s}{s^2 + a(Wo)s + (wo)^2}.$$

The reason for using this arrangement is that the midband voltage gain and the center frequency of the notch are easily adjustable. R3 adjusts the midband gain and R4 adjusts the center frequency. The center frequency can be adjusted over a full decade, 25 to 250 Hz, while maintaining a constant notch width of 10 Hz. Decreasing C5 and C6 by an order of magnitude will increase the center frequency and the notch width by an order of magnitude. The bode plots of Figures 13 through 16 show the versitility of this circuit.

Figure 17 shows the results of filtering the actual test data with the notch set at 38.75 Hz and the low-pass cutoff set at 149.7 Hz. Recall the data is being played back at a reduced speed so this would correspond to having a notch at 310 Hz and a low-pass cutoff of just under 1200 Hz in real time.

Even though this notch removed the major noise

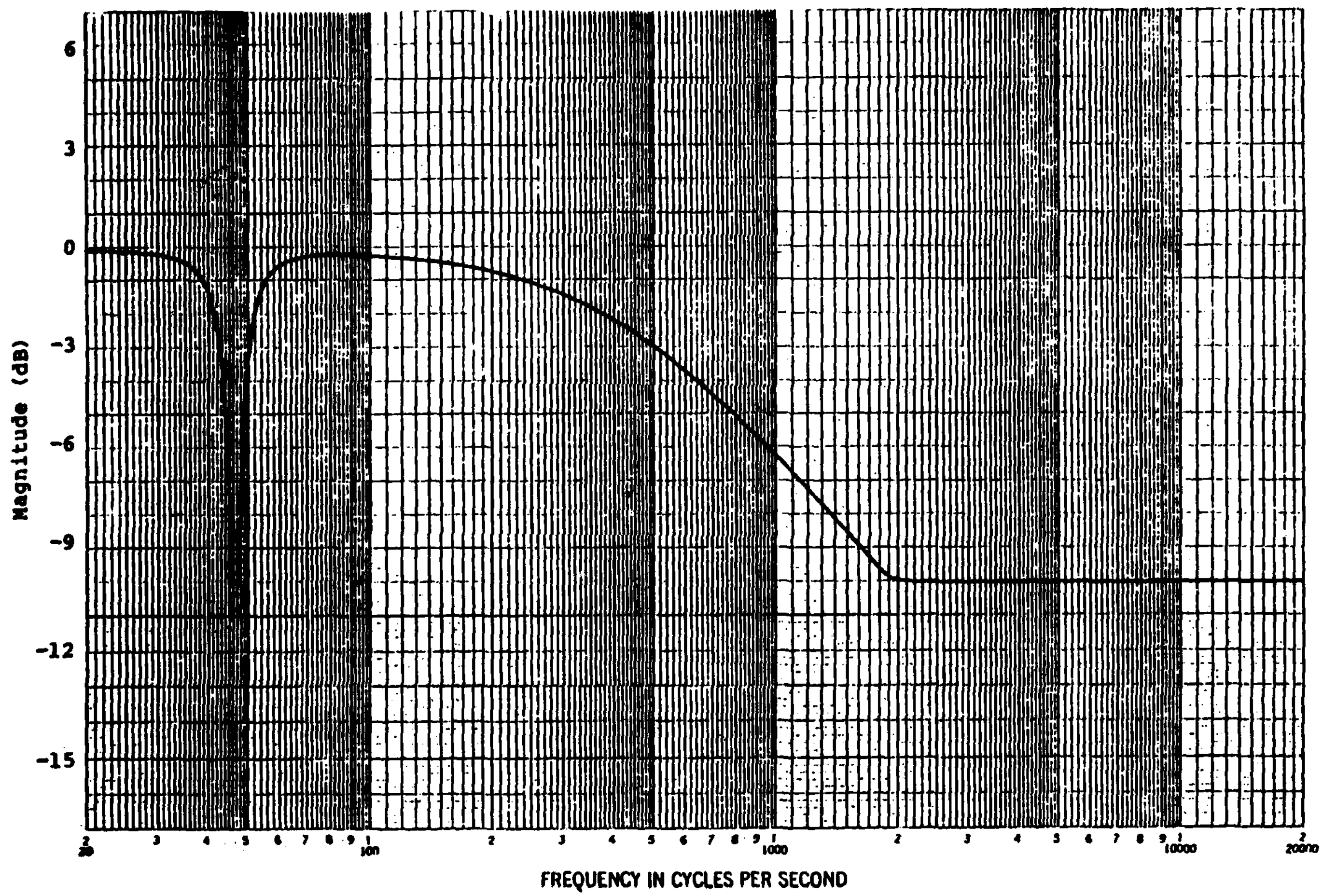


Figure 13. Bode Plot of Filter (Notch = 46.5 Hz, Low-Pass = 500 Hz)

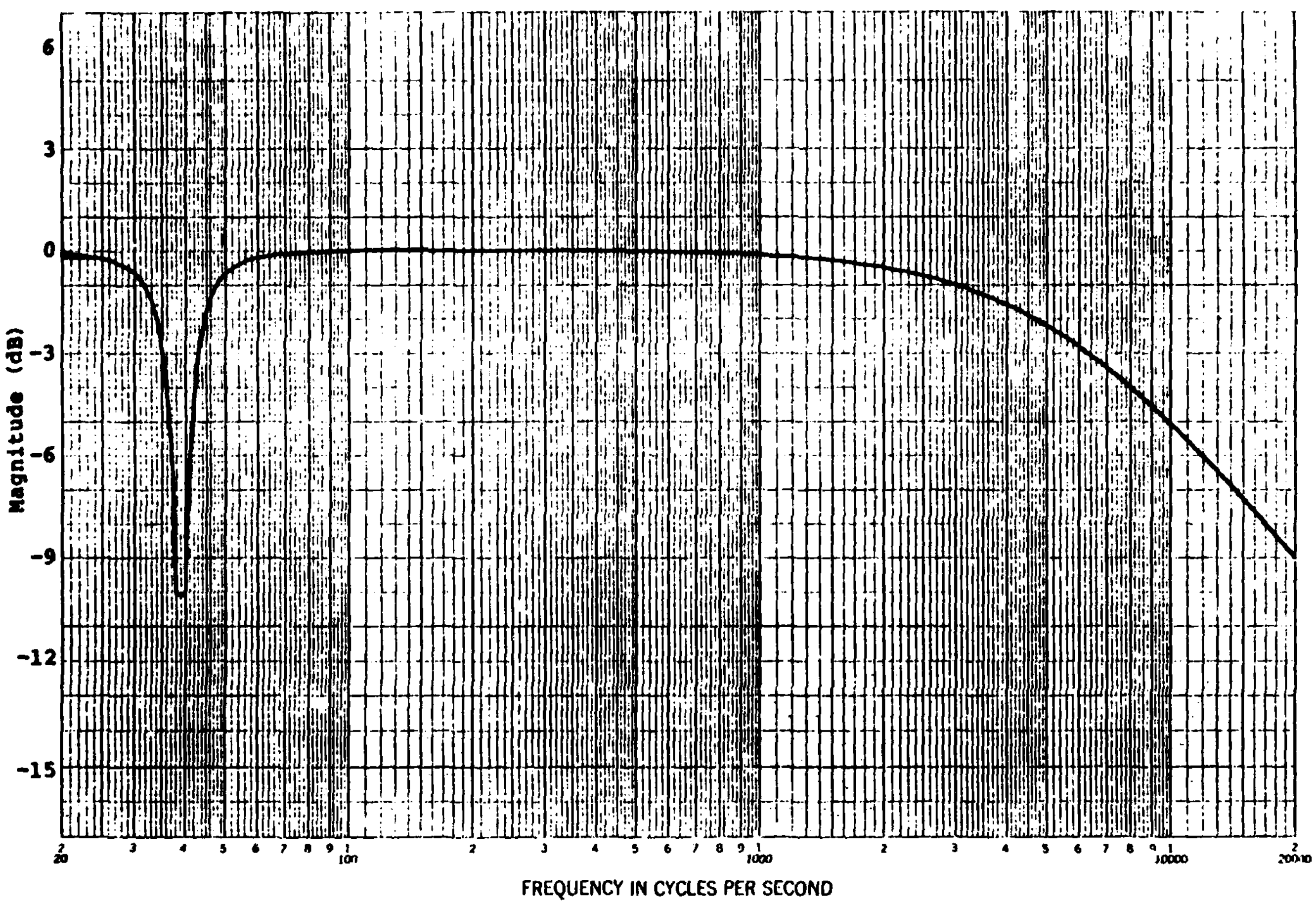


Figure 14. Bode Plot of Filter (Notch = 39 Hz, Low-Pass = 6300 Hz)

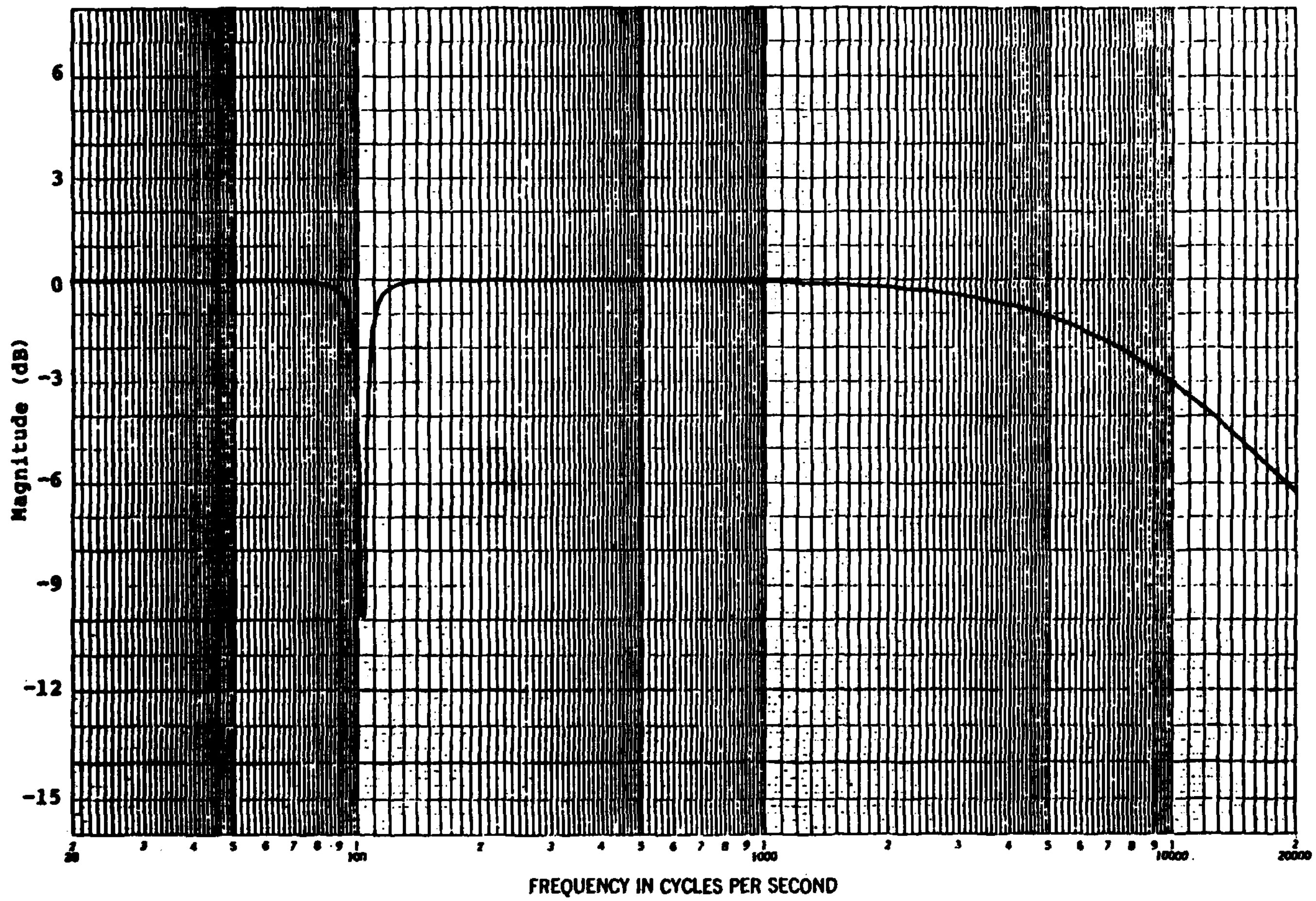


Figure 15. Bode Plot of Filter (Notch = 103 Hz, Low-Pass = 10 kHz)

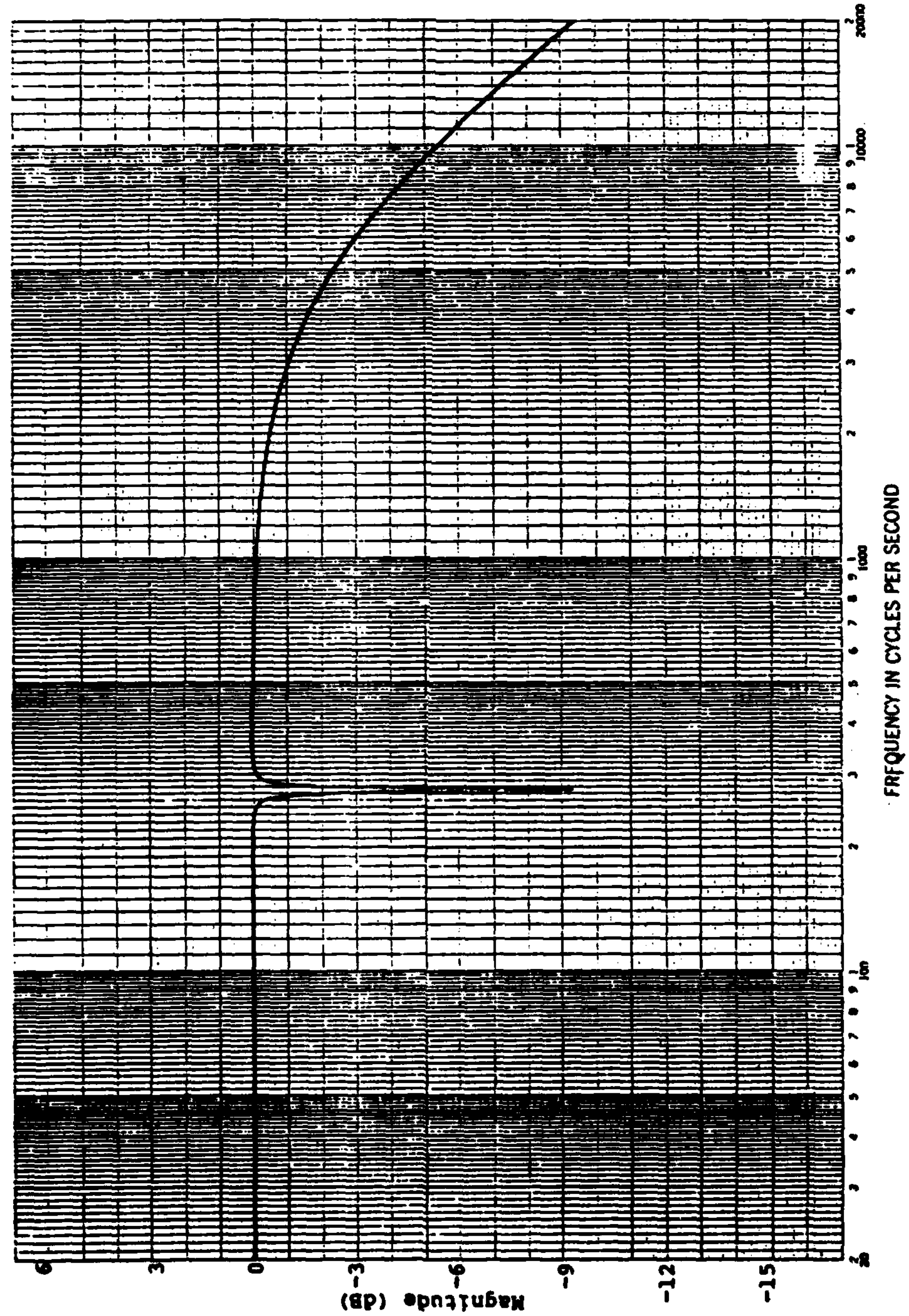


Figure 16. Bode Plot of Filter (Notch = 277 Hz, Low-Pass = 6 kHz)

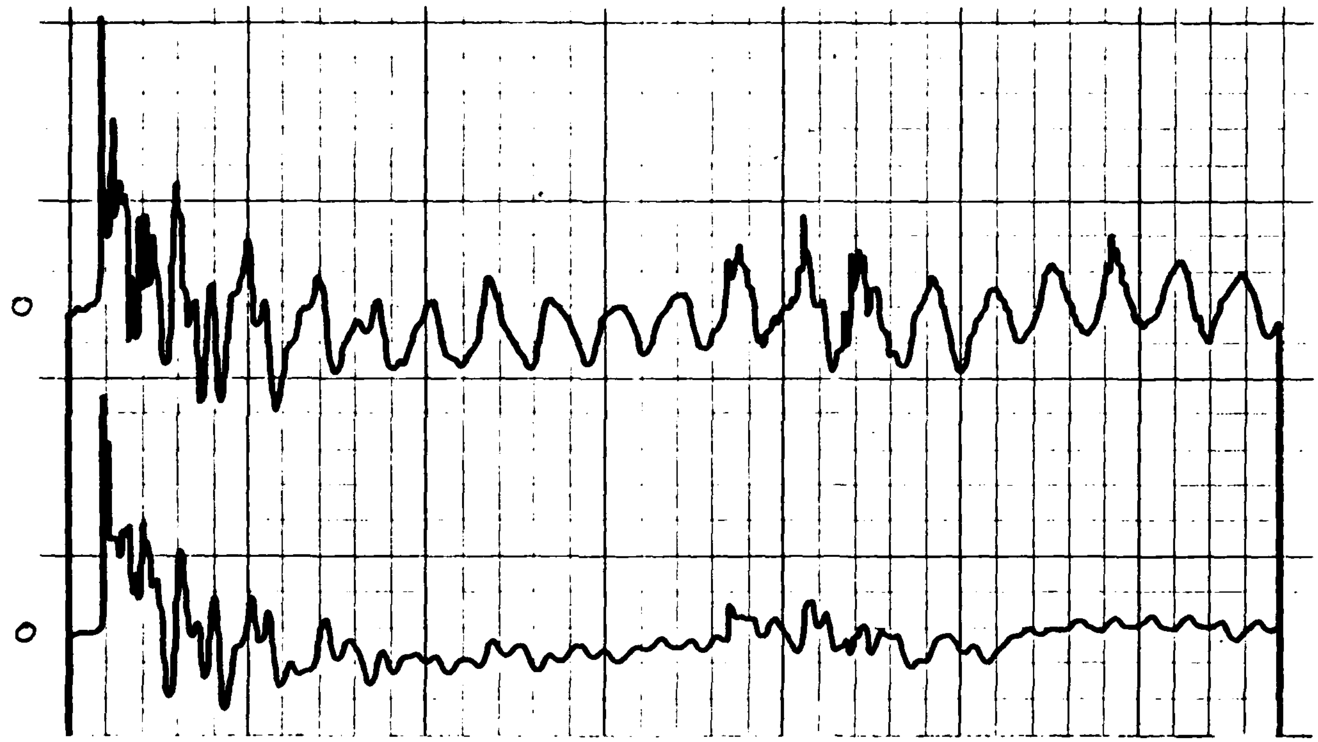


Figure 17. Data After Analog Filter (Notch = 38.75 Hz, Low-Pass = 149.7 Hz). Top trace is Raw Data and bottom trace is filtered data. The horizontal direction is time, approximately 1.88 msec. per small division. Vertical Scale is voltage each small division is approximately 80.3 mV..

signal from the data, additional notch filters would be required to smooth the data properly. These would be set for the second and third harmonics of the original notch. Also a 60 Hz (480 Hz real time) notch seemed to remove some of the noise. In all then one would need a minimum of four notch filters in addition to the low-pass filter, to properly condition this signal.

The set-up and adjustment of this many filters would be very time consuming. I estimated that with practice and the aid of a spectrum analyzer, a technician could process one signal in just under under four hours. Realizing that a given test may produce 20 to 50 such signals shows that the man-hour cost would probably be prohibitive. Attempting to do this kind of filtering without the aid of a spectrum analyzer would be unthinkable.

A much more accurate and faster method of filtering the data would be to digitize the data and then use the computer to remove the noise.

Although numerical smoothing is a form of digital filtering, I have separated them in the following sections. In this thesis, digital filtering indicates a frequency domain manipulation, while numerical smoothing operates only on the time domain signal.

4. Digital Filter

Fourier analysis has been around for a long time, but it has only been since the advent of the large memory, high speed, digital computers that the use of this method for filtering has been feasible.

The Fast Fourier Transform (FFT) is an efficient algorithm for computing the discrete Fourier transform. Using the FFT, one can compute the Fourier transform of a signal, decide what frequency components in the signal are not wanted, remove all or part of them, and then return the signal to the time domain as a filtered version of the original signal.

Although a simplified description of digital filtering, this is in essence what a digital filter accomplishes. The big advantage of a digital filter over its analog counterpart is the ability to rapidly and precisely change the characteristics of the filter to match the situation. An analog filter has to make a change in hardware while the digital filter only has to change some bits in memory.

For the particular problem of filtering the blast wave data, the first task was to convert the analog signal to a digital signal (Figure 18). The analog signal was passed through a low-pass filter whose cutoff frequency was less than one half the sampling rate of the analog to digital converter (ADC). This procedure

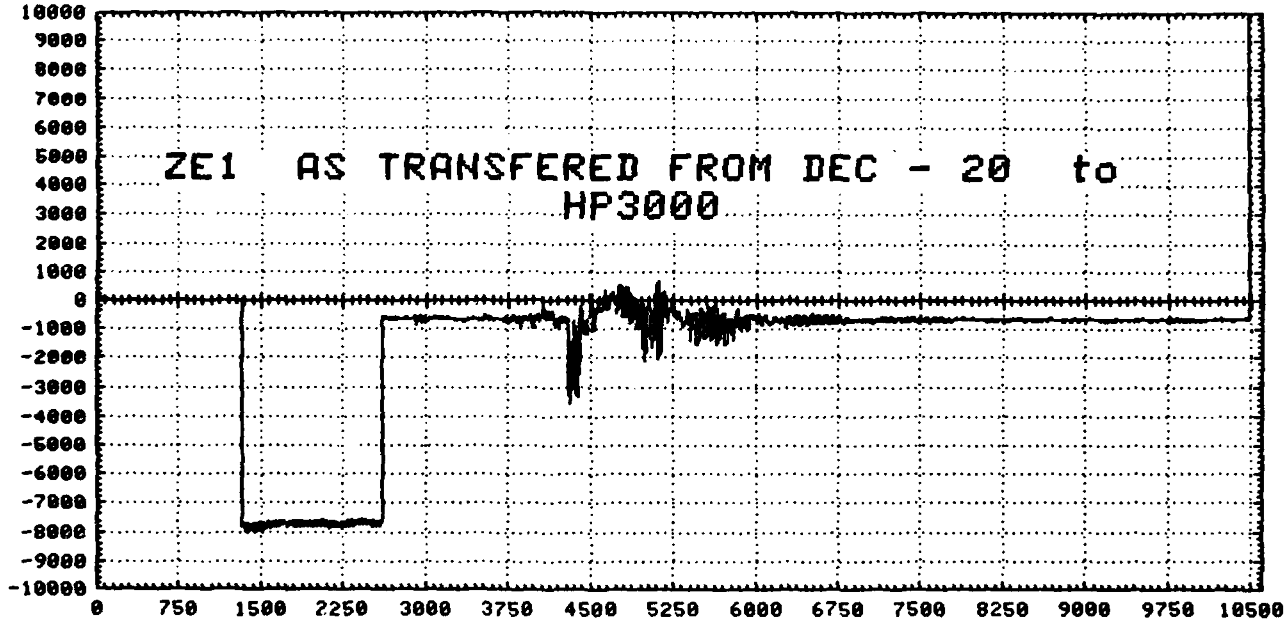


Figure 18. Raw Digitized Data (Same Original Data as Figure 9)

assures that the sampling rate will be at least twice the highest frequency component of the data and minimizes the noise added by the ADC.

Once the data is digitized, it must be converted to units of pressure (psi) to be meaningful. Program Slope (Appendix C) accomplishes this. The program reads the calibration information at the beginning of the data, asks the operator what pressure this data represents. The program then computes a slope and intercept, which is applied to each data point. The particular data I used was inverted in the process of digitizing, therefore, this program will invert the data again to return it to its proper phase (Figure 19).

At this point the data must be edited to remove all signal prior to the initial rise of the blast wave. This editing is done because program Filter assumes that the blast wave begins at time equal to zero. If the editing is not done, a phase shift will result in the filtered data.

The final step is to actually filter the data using program Filter (Appendix D). This program asks the operator for several pieces of information. First it asks for equivalent explosive weight and the distance to ground zero. It must have this information to compute the ideal blast wave. The next request the computer makes is for the power of two for the FFT. The number

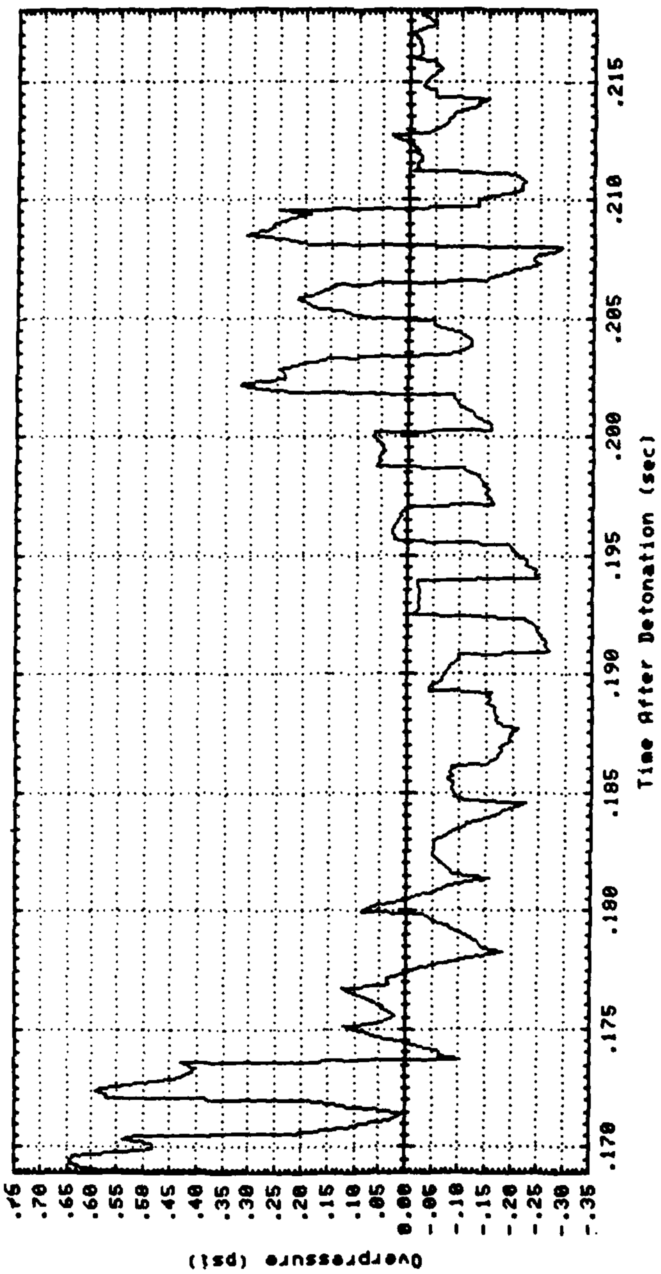


Figure 19. Digitized Data Converted To Engineering Units

input at this point will determine the resolution of the frequency spectrum computed for both the ideal and actual blast waves. It should be such that two raised to this power is greater than twice the number of data samples in the actual data and at the same time less than 4097 to prevent going outside the bounds of the program.

The next request of the program is for the operator to input the time per sample for the actual data. This is used to correlate the ideal blast wave to the actual data.

The final request is to input the desired percent of peak overpressure (95-100). If the response is 100, then the Frielander approximation is used, but if 95-99 is chosen then equation (3) is used with the appropriate value selected for the cutoff frequency. In most cases, this choice will make very little difference in the output data. Therefore, I recommend 100% be used to decrease the computation time slightly.

At this point, the program computes the ideal blast wave and its FFT. Then the FFT of the actual data is computed. Since the amplitude of an FFT is proportional to the amplitude of the original signal, one can compare the magnitudes of the two FFTs. Comparing the magnitudes of the FFTs, the program substitutes the value of the FFT of the ideal blast wave for any point in the FFT

that the actual exceeds the ideal by 2.5%. This procedure has the effect of removing only enough of the unwanted frequencies to remove the noise.

Program Filter requires that the guess for the explosive weight be higher than the actual explosive weight. Otherwise, the output data would just be a reproduction of the ideal blast wave for that guess. If after the first try the data is still noisy, the program could be run again with a lower guess for the explosive weight.

The time required for this form of filtering is going to be dependent on the type of computer used, but should be much faster than attempting to do the filtering in an analog fashion. The excellent results of this method are shown in Figure 20, the filtered version of Figure 19.

Although this program reads the data from a file in the computer and puts the resulting data into another file, there is an underlying assumption that the computer has the ability to plot the data. Otherwise, it would be of very little benefit to the using agency.

There is always more than one way to accomplish a given task, and so it is in this case. The following section presents a time domain method to remove the noise.

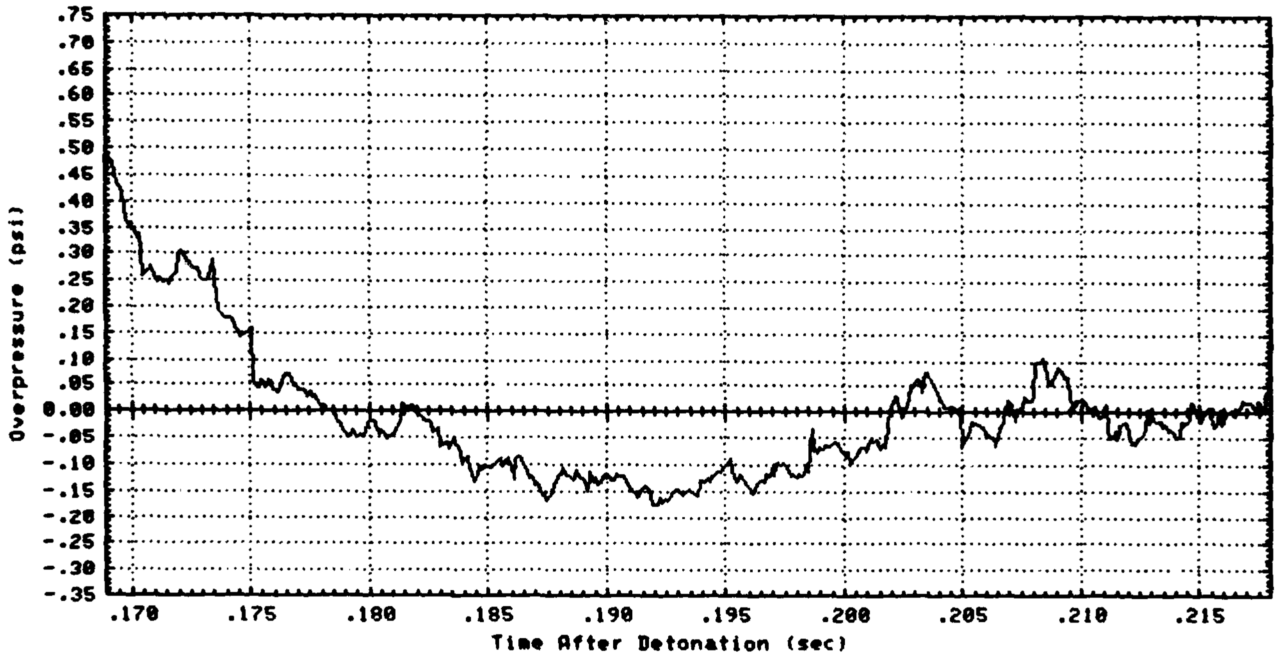


Figure 20. Data After Digital Filtering

5. Numerical Smoothing

A popular method[2] of smoothing data is the method of least squares. It is the approach I have taken here.

Two conditions must be met to compute an estimate of data using the method of least squares. First there cannot be any systematic errors in the estimate (i.e. no bias). For the blast wave data, the average of the noise is zero. Therefore, there is no bias.

The second condition is that the points computed as a result of the least squares estimation should be linear functions of the measurement data. This condition creates a minor problem. The ideal blast wave is not a linear function of time. Therefore, I made a slight change to the standard least squares technique; I call it the "sliding least squares."

Since the blast wave can be approximated by a series of straight line segments, I wrote a program which would compute a sliding least square fit to the blast wave data (Program Smooth, Appendix E)

The program asks the operator for the number of samples to "average," call it (n) samples. Then the computer reads (n) samples from the data file, computes a standard least squares fit to these points, and outputs the first (n/2) points according to this least square estimate.

---

[2]G. Dahlquist and A. Bjorck, Numerical Methods, translated by N. Anderson, (Prentice-Hall, Inc., New Jersey, 1974), pp. 126-129.

At this point the sliding starts. The elements of the array holding the first (n) samples are shifted one place to the left. The first data sample is discarded and the (n + 1) sample is read into the nth position of the data array. A new least square estimate of the data is now computed and used to compute the (n/2 + 1) data point. Here the process starts over again by shifting the data array one place to the left reading in a new point, etc.

If the end of the data file is reached before the specified number of points have been calculated, the last few points (as many as n/2) are calculated according to the latest least square estimate.

The result of this method is shown in Figure 21, the original test data was that of Figure 19.

Once the noise is removed, standard methods can be used to determine the positive phase integral and the peak amplitude. The actual explosive equivalence of the charge being tested can be determined from these two parameters.

If the data is digitized as it is being collected, the process of smoothing could be done in about the same amount of time as it takes to convert the data to engineering units. This means a digital data acquisition system.

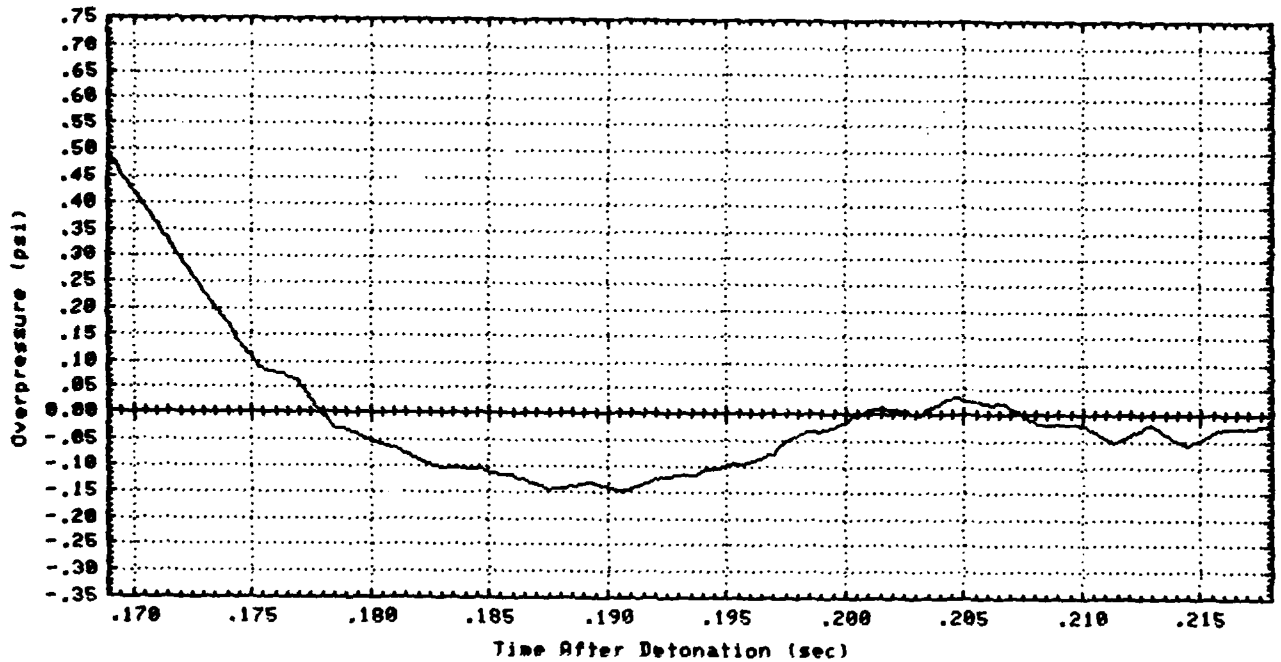


Figure 21. Data After Numerical Smoothing

DIGITAL TELEMETRY SYSTEM

An analog system has several disadvantages. First is the limit on the number of channels of data that can be recorded (the number of channels on a tape recorder). Second is the fact that two power wires and a coax cable must be run to each transducer, which means that once the transducers are located, they are pretty well permanent. Third, the data must be digitized before it can be analyzed by a computer. The proposed system will eliminate these restrictions.

It is a system using one Central Control Unit (CCU) and many Field Units (FU). The number of channels will only be limited by the number of transducers that each FU can service and the size of computer word used to address the individual FUs. In general the CCU will be a 16 bit computer capable of addressing up to 1000 FUs via radio signals (2-3 GHz). Each FU must be able to service at least eight (8) transducers with an overall throughput rate of 50 000 data samples per second.

1. Central Control Unit

This unit acts as the "brain" of the system. Prior to the test it will automatically check all of the FUs

to see if they and their peripherals are operational and ready. When the time comes for the test, the CCU will tell the FUs to start recording data at the proper times. Further, the CCU will start the cameras and even detonate the test item through the FUs. After the test is over, the CCU will instruct each of the FUs, one at a time, to transmit the recorded data back to the main computer for storage and analysis at a later time. Finally, the CCU will make a post operational check of each of the FUs and "flag" any unit that is questionable, thereby, allowing that unit to be checked immediately for the cause of the problem and a possible data bias. At this point, the data could either be recorded on tape and sent to the main computer on base for analysis, or it could be digitally filtered as discused above and then recorded and sent to the base for further analysis.

The CCU will consist of an electronic, digital computer (minicomputer or main frame) and a radio transceiver operating in the range of 2-3 GHz connected by the appropriate interface.

The computer shall be programable in a high level language (Fortran, Algol, or Pascal), with instructions which permit the addressing of peripherals from within the program. As a minimum this computer must have the computing power and internal memory (one megabyte)

equivalent to an HP3000/33, with some form of graphics capability (i.e. be able to make two-dimensional, hard copy plots of data).

The following peripheral equipment is required:

1. One (1) multisurface disc memory, with expansion capability to five (5) such units. Each unit shall have a minimum of 120 megabytes of disk storage.

2. Industry standard, IBM compatable, magnetic tape drive, nine (9) track, capable of reading and writing 1600 bits per inch.

3. A video type terminal with graphics.

4. Lineprinter.

5. Graphics printer.

6. Transceiver.

7. Card reader.

The above items could be combined, for example; items 3, 4, and 5 could be provided in one unit, the HP 2648A Graphics Terminal/Printer.

In addition to the above, a minimum of five (5) extra peripheral ports must be included with at least two (2) being serial RS-232C compatible and at least one (1) shall be a 16 bit parallel port. These would be available for future expansion of the system.

The computer shall have a diagnostic program to aid in trouble-shooting repair problems. This program will diagnose problems down to the "board" level, internally,

and indicate the peripheral port in the case of external problems.

One further requirement of the CCU is that it be able to address, through the transceiver, each of the FUs individually as well as collectively, individually to allow for checking of status and to transmit data, and collectively for starting time messages etc.

The transceiver interface to the computer shall be designed to accept transceivers manufactured by at least two (2) different companies and the interface shall be independent of the type transmission used by the transceiver.

2. Transceivers

The exact format for the transceiver shall be left to the discretion of the contractor. It will be a form of Frequency Modulation with some arrangement to insure positive communication is established before significant information is transmitted. The framing arrangement for the data transmission will likewise be left to the discretion of the contractor. The minimum acceptable range for the telemetry system is 25 miles.

Application will be made to the Federal Communication Commission for a specific frequency, bandwidth, and power allocation just prior to releasing the contract for bids.

The transceiver in the FU will obviously have to be compatible with the one in the CCU. The FU transceiver must occupy no more than 216 cubic inches and be battery powered. The CCU will use the most efficient antenna possible, while each of the FUs will use only the minimum possible antenna to limit the area they present to the blast wave and also limit the cost. As presently planned, the CCU will be located in line-of-sight with the FUs and slightly higher than the FUs. If the test site location is ever changed, a repeater will probably have to be installed to handle the transmission.

3. Field Unit

Each FU is a totally independent unit and operates entirely on its own once a start signal is received. The FU must be able to check itself and the transducers connected to it, and then transmit a status report of both to the CCU. It must be capable of determining when to start and stop recording data. The FU must be capable of sampling and recording data at rates up to and including 50 000 samples per second, overall throughput, from programably selectable channels.

When the signal is received from the CCU that the test item will detonate in a given amount of time, several events must take place in the FU. First a real-time countdown clock is started. Second, two calibration

values are read for each transducer and recorded as the first two pieces of data for each transducer. These calibration values are to be a voltage substition type, with the calibration voltage switched into the system prior to the first amplification. One voltage represents the highest expected output of the transducer the other is to be zero volts. These calibration values must be accurate to within 0.1% of the desired value. Third, a relay closure (1.5 amperes max, 120 volts ac) must occur at a preprogrammed time, plus or minus 0.5 milliseconds.

The ability of the FU to provide a relay closure, at a precise time prior to detonation, is for starting cameras or even detonation of the test item.

The fourth event will be to start recording data from the preprogramed number of transducers at the appropriate sampling rate. This data will be rotated in memory until actual data (rise of the blast wave) is detected. Then the data 10 milliseconds prior to the rise and 240 milliseconds after the rise will be recorded and stored. Also stored for each transducer will be the real-time clock word corresponding to the first data sample.

The fifth event is a post-calibration, to be performed identical to the first one. With these two pieces of information stored as the last two words in

the data file. This post-calibration should take place at least 30 seconds after the last data sample is acquired.

The final event the FU must accomplish on its own control is to output the data to a cassette recorder. This could be started as soon as the post-calibration is complete. The data is to be put on the cassette one transducer at a time with enough leader information to identify the transducer location, time, and date of the test.

The last event of the test would be for the CCU to sequentially have each of the FUs transmit the data they collected back to the CCU in the same format as the FU used to record the data on cassettes.

The FU should be versatile enough that any of several types of transducers could be connected with little or no modification to the FU. The FU must be battery operated to eliminate the need to run any power lines or signal lines at all except to the transducers it services. This battery must be capable of operating the FU continuously for up to four (4) hours.

The FU consists of a transceiver, connected via an appropriate interface to the microprocessor. The microprcessor controls all the functions mentioned above and acts as a traffic controller to pass data from either method of storage to the transceiver for

transmission to the CCU. The microprocessor will be 16 bit with a sufficient instruction set to accomplish the above described tasks.

The random access memory (RAM) shall be sufficient to store 12 500, 16 bit, samples plus the necessary program instructions. If the sampling rate is 50 000 samples per second, this represents 250 milliseconds of signal data, which is twice that of most of the signals measured during the testing of 1980. The erasable, programable, read-only memory (EPROM) is used to store the program so it can easily be changed to accommodate changes in use of the FU. For example, suppose digital signals were being received from several different velocity transducers instead of the digitized signal from the ADC, a different format might be required to map the data into memory. Definitely, there would be big differences in the self-test function and therefore, a modified program would be required.

Of the channels each FU sevices, at least four (4) will be analog and four (4) will be digital. The digital channels will be 16 bit parallel ports.

Each of the analog channels will have an adjustable gain amplifier (1-1000) with a selectable input impedance of 50 ohms or 10 megohms, also to be selectable is single or differential input. Each of the analog channels will incorporate a single-pole, low-pass filter whose cutoff

frequency (-3 dB) is continuously adjustable from 100 Hz to 20 kHz. The amplifier must have a constant gain down to and including dc.

The multiplexer must be able to select any combination of the analog channels with uniform sampling over those channels selected.

The ADC must accept a full scale input of plus to minus 10 volts and provide at least 12 bit resolution, including sign, at the output. This is to be accomplished at a minimum throughput rate of 50 000 samples per second.

The data acquisition section of the FUs will meet or exceed the following specifications:

Accuracy: 0.025%

Stability: 0.025%

Temperature Coefficient: 0.01%/°C (from 0-70 °C)

Linearity: 0.025%

Repeatablity: 0.025%

Sample and Hold: < 100 nanosecond aperature uncertainty

Output code: Binary

Crosstalk: < 0.025%

Common Mode Rejection: >75 dB

Noise, 3 sigma: < 600 microvolts, peak-to-peak

The interface between the microprocessor and the transceiver must be similar to the one specified for the CCU in that it must accept transceivers manufactured by at least two different companies.

The EMP of the explosion can be quite large, depending on the size of the explosion and distance from ground zero. Therefore, an additional requirement of the FU will be to electically disconnect the antenna from the front-end of the transceiver one second prior to detonation and reconnect it about one minute after the detonation. This will help prevent the transceiver from being damaged by the EMP. Both the antenna and the transceiver front-end should be connected to ground during this period.

The final requirement of the FU is that it fit in a box 2 ft x 2 ft x 2 ft. This box will be buried in the ground with the top of the box flush with the ground. This box, therefore, will have to be air and water tight. The antenna can be mounted on the top of the box and feed-throughs for the transducers can be mounted on the sides of the box. The FU must be able to operate in this environment and it must be easily removeable from the box (i.e. disconnect antenna and transducers, lift the FU from the box).

The initial cost of this system may be more than a comparable analog system, however, the versitility and

portability make the telemetry system much more useable. Further, in the long run this system will save money, because the cost to change transducer locations should be cut by a factor of ten, other savings will be realized in data reduction.

RECOMMENDATIONS

To produce data that will be readily usable by the requesting agency, I recommend that the above specified digital acquisition system be purchased and used when testing explosive items. Further, the use of Figure 8 and Appendix F to set the cutoff frequency of the low-pass filter will help reduce the noise recorded and also allow the actual peak overpressures to be calculated from the recorded data.

Once the data is recorded, it should be filtered with one of the two programs provided in Appendices D and E. This will give the using agency the most ideal data possible to use in their calculations and decisions.

APPENDIX A

PROGRAM RESPONSE

```
      program RESPONSE
c****************************************************
c*   This program was developed as part of an Electrical
c*   Engineering Thesis by Theodore J Moody, entitled,
c*   "Instrumenting an Explosive Test Arena," at the
c*   University of Utah, May 1982.
c****************************************************
$control nolist
$control file=25-39
      i2p = 9.0
      n = 2**i2p
c************************************
c*  Operator inputs a guess for the pole location
c************************************
      display 'input pole multiplier'
      accept pmult
        l = 0
        do 1500 l1 = 1,4
        display '  Lambda    LPF cutoff Hz    Peak'
         do 1000 l2 = 1,50
          l=l+1
c************************************
c*    Lambda = range/(explosive weight ^(1/3))
c*        where xlam = lambda
c*              r = range
c*              wt = explosive weight
c*    This parameter is from The Air Force Technical
c*    11A-1-47, Department of Defense Explosive Hazard
c*    Classification Procedures, March 1981.
c************************************
      xlam = 10.0**((0.0165*(float(l)))-0.301)
c************************************
c*     The peak overpressure and impulse described in
c*     in this TO are only described for 0.5<lambda<1000.
c************************************
c************************************
c*     The impulse of the peak overpressure is known only
c*     experimentially, therefore, two equations are
c*     needed to decribe the positive impulse;  one for
c*     the range 0.5<lambda<2.o48 (the equation following
c*     label 410) and one for the range 2.048<lambda<1000
c*     (the equation with label 420).
c*                 ximp = Positive impulse
c*     The following calculates the value of the impulse
c*     for the given lambda.
c************************************
      x1 = 40.0
      y1 = 0.05
      x2 = 2.048
      y2 = 11.474
      x3 = 1.442
```

```
      y3 = 13.16
      x4 = 1.0
      y4 = 20.0
      xil = alog10(xi)
      yil = alog10(yi)
      x21 = alog10(x2)
      y21 = alog10(y2)
      x31 = alog10(x3)
      y31 = alog10(y3)
      x41 = alog10(x4)
      y41 = alog10(y4)
      a = (yil-y21)/(xil-x21)
      b = yil - a*xil
      b = 10.0**b
      c = ((y31-y41)*(x21-x41)-(x31-x41)*(y21-y41))/
     1     (((x31*x31-x41*x41)*(x21-x41))-((x31-x41)*
     2     (x21*x21-x41*x41)))
      d = (y21-y41-c*(x21*x21-x41*x41))/(x21-x41)
      e = (y41-(c*x41*x41)-d*x41)
 410  if(xlam.ge.2.048)go to 420
c*****************************************************
c*    Calculates impulse if in parabolic portion
c*****************************************************
      f = alog10(xlam)
      g = (c*f*f)+(d*f)+e
      ximp = (10.0**g)
c*****************************************************
c*    Calculates impulse if in linear portion
c*****************************************************
      go to 430
 420  ximp = b*((xlam)**a)
 430  continue
c***********************************
c*     Sends lambda and weight to files number 31 and 32
c***********************************
      wt = (1.0/xlam)**3.0
      write(31)xlam
      write(32)ximp
c*****************************************************
c*   The following equations are from an article by
c*   L. Giglio-Tos and T.E. Linnenbrink, "Air Blast
c*   Pressure Measurement Systems and Techniques",
c*   MINUTES, 15th DODESB Seminar, September 1973,
c*   p. 1400.  Although the equations in the reference
c*   have considerable overlap, Lambda = 71.725155 was
c*   choosen as the change over point because this is
c*   the point where the two equations are equal (to
c*   9 decimals).
c*   The first equation calculates the peak overpressure
c*   (pm) in the range  0.5<pm<71.725155
c*****************************************************
      if(xlam.gt.71.725155)go to 440
```

```
      xlnpm = 7.0452041-1.6277561*(alog(xlam))-0.27399088*
     1         ((alog(xlam))**2)
     2         -0.065973136*((alog(xlam))**3)+0.0065412563*
     3         ((alog(xlam))**4)
     4         +0.048236359*((alog(xlam))**5)-0.020072553*
     5         ((alog(xlam))**6)
     6         +0.0030190449*((alog(xlam))**7)-0.00015984026*
     7         ((alog(xlam))**8)
      pm = exp(xlnpm)
      go to 450
c***********************************************************
c*   Calculates peak overpressure (pm) in the range
c*             71.725155<pm<1000.0
c***********************************************************
 440  pm = 226.61762/((xlam)**(1.4065913))
c***********************************************************
c*    Calculates the time of the positive phase of the
c*    blast wave (xto) from an analytical integral
c*    solution of the ideal blast wave.
c***********************************************************
 450  xto = 0.001*ximp*2.718281828/pm
c***********************************
c*    This equation is derived from solving the integral
c*    of            p(t) = pm*exp(-t/to)*(1-t/to)
c*    the Frielander Approximation to a Blast Wave, in
c*    combination with the above equations for pm.  The
c*    object is to find the time the overpressure
c*    returns to ambient (xto).
c***********************************
      write(33)xto
      write(34)pm
c***********************************************************
c*  The following uses equation (3) developed in the main
c*  part of the theses Section A
c*  This calculates the value of y(t)  until a maximum is
c*  detected, then outputs the maximum and calculates the
c*  Range-Bandwidth Product
c***********************************************************
      to=xto
      pi = 3.141593
      ainc = pi/to
      a = 0.0
      tinc = to/10000.0
      a = pmult*ainc
      ato = a*to/(a*to-1.0)
      t = 0.0
      ynm1 = -1.0
      do 100 i = 1,9000
      t = t+tinc
      b = -t/to
      c = exp(-a*t)
      d = exp(b)
```

```
      yn = ato*((1.0+b)*d-c)+(d-c)*(ato/(a*to-1.0))
      if(yn.lt.ynmi)go to 200
 100  ynmi = yn
 200  yn = ynmi
      t = t-tinc
      a = a/(2.0*pi)
      display xlam,a,yn
      write(35)a
1000  continue
1500  continue
      endfile 31
      endfile 32
      endfile 33
      endfile 34
      endfile 35
      stop
      end
```

APPENDIX B

PROGRAM SPECTRUM

```
        Program SPECTRUM
c**********************************************************
c*   This program was developed as part of an Electrical
c*   Engineering Thesis by Theodore J Moody, entitled,
c*   "Instrumenting an Explosive Test Arena," at the
c*   University of Utah, May 1982.
c**********************************************************
c*************************************
c*   This program reads a file, takes the Fourier Transform
c* of that file and outputs the Magnitude of the transform
c* and the Power Spectrum.
c*************************************
$control nolist
$control file=25-29
        dimension u(4096),v(4096),w(4096)
c**********************************
c*   Reads data from file ftn25 designated by the operator
c**********************************
        do 100 k = 1,4096
        read(25,end=120)u(k)
        v(k) = 0.0
 100    continue
        display ' Read data '
 120    k = k-1
c*************************************
c*   Operator selects the power of two for FFT
c*************************************
 125    write(6,130)
 130    format(1x,24hPower of 2 for the FFT =)
        read(5,*)i2p
 140    format(I5)
        n = 2**i2p
        nm =n-1
        if(n-k)142,155,145
 142    write(6,143)
 143    format(1x,20hPower of 2 too small)
        go to 125
 145    if(n.lt.4097)go to 147
        write(6,146)
 146    format(1x,20hPower of 2 too large)
        go to 125
 147    do 150 j = (k+1),n
        u(j) =0.0
        v(j) =0.0
 150    continue
 155    continue
        pi = 3.141592654
c*********************************
c*   Developes window to properly condition the data
c*   before transforming.  Uses the Blackman window
c*********************************
```

```
        do 170 j = 1,n
        w(j)=0.42-(0.5*cos(2*pi*(j-1)/nm))
     1        +(0.08*cos(4*pi*(j-1)/nm))
 170    continue
        display ' Window built '
        ns = n/2
c******************************
c*   Shifts window over data
c******************************
        call shift(w,n,ns)
c*******************************
c*   Windows data
c*******************************
        do 180 j =1,n
        u(j) = w(j)*u(j)
 180    continue
        display ' data windowed'
c****************************
c*   Takes Fourier Transform
c****************************
        call nufft(u,v,i2p,1)
        do 185 j=1,n
        write(28)u(j)
        write(29)v(j)
 185    continue
        display ' FFT filed'
        endfile 28
        endfile 29
        ymax = 0.0
        ymin = 1000.0
        zmax = 0.0
        zmin = 1000.0
c*******************************
c*   Determines Magnitude of transform
c*******************************
        do 190 j = 1, n
        u(j) = sqrt((u(j)**2)+(v(j)**2))
c******************************
c*   Determines the maximum and minimum values of
c* the magnitude
c******************************
        if(u(j).gt.ymax)ymax = u(j)
        if(u(j).lt.ymin)ymin = u(j)
c*****************************
c*   Outputs Magnitude to file ftn26
c*****************************
        write(26)u(j)
c*********************************
c*   Determines the Power Spectrum of the transform
c*********************************
        v(j) =10.0*alog10(u(j))
c***********************************
```

```
c*   Determines the maximum and minimum values of
c* the Power Spectrum
c***********************************
        if (v(j).gt.zmax)zmax = v(j)
        if (v(j).lt.zmin)zmin = v(j)
c***************************************
c*   Outputs the Power Spectrum to file ftn27
c***************************************
        write(27)v(j)
 190    continue
        display ' Magnitude and Power Spectrum Filed'
c*************************************
c*   Outputs maximun and minimum values of the Magnitude
c* and the Power Spectrum to the teletype
c*************************************
        write(6,200)ymax
        write(6,210)ymin
        write(6,220)zmax
        write(6,230)zmin
 200    format(1x,24hFreq Magnitude MAXIMUM =,f12.5)
 210    format(1x,24hFreq Magnitude MINIMUM =,f12.5)
 220    format(1x,24hPower Spectrum MAXIMUN =,f12.5)
 230    format(1x,24hPower Spectrum MINIMUM =,f12.5)
        endfile 26
        endfile 27
        stop
        end
C**************************************
C*       This is a subroutine to perform the Fast
C*       Fourier Transform (FFT) of a complex array
C*       where:
C*              XR = Real array
C*              XI = Imaginary Array
C*               M = The order of the FFT (2^M)
C*              IDIRN = The direction of the Transform
C*                      1 = forward
C*                     -1 = reverse
C*       The result returns in XR and XI
C**************************************
        SUBROUTINE NUFFT(XR,XI,M,IDIRN)
        DIMENSION XR(1),XI(1)
        N=2**M
        PI=3.1415927
        DO 20 L=1,M
        LE=2**(M+1-L)
        LE1=LE/2
        UR=1.0
        UI=0.0
        WR=COS(PI/FLOAT(LE1))
        WI=-SIN(PI/FLOAT(LE1))
        DO 20 J=1,LE1
        DO 10 I=J,N,LE
```

```
        IP=I+LE1
        TR=XR(I)+XR(IP)
        TI=XI(I)+XI(IP)
        TMR=XR(I)-XR(IP)
        TMI=XI(I)-XI(IP)
        XR(IP)=TMR*UR-TMI*UI
        XI(IP)=TMR*UI+TMI*UR
        XR(I)=TR
10      XI(I)=TI
        TR=UR*WR-UI*WI
        UI=UR*WI+UI*WR
20      UR=TR
        NV2=N/2
        NM1=N-1
        J=1
        DO 30 I=1,NM1
        IF(I .GE. J) GOTO 25
        TR=XR(J)
        TI=XI(J)
        XR(J)=XR(I)
        XI(J)=XI(I)
        XR(I)=TR
        XI(I)=TI
25      K=NV2
26      IF(K .GE. J) GOTO 30
        J=J-K
        K=K/2
        GOTO 26
30      J=J+K
        IF(IDIRN .EQ. 1) GOTO 77
        DO 99 I=1,N/2
        TTR=XR(I)/N
        TTI=XI(I)/N
        XR(I)=XR(N-I+1)/N
        XI(I)=XI(N-I+1)/N
        XR(N-I+1)=TTR
        XI(N-I+1)=TTI
99      CONTINUE
        TTTR = XR(N)
        TTTI=XI(N)
        DO 777 I=N,2,-1
        XR(I)=XR(I-1)
        XI(I)=XI(I-1)
777     CONTINUE
        XR(1)=TTTR
        XI(1)=TTTI
77      RETURN
        END
C**********************************************************
C*      THIS SUBROUTINE SHIFTS THE ARRAY TO THE RIGHT
C*     N/2 SAMPLES IN A CIRCULAR SHIFT
C**********************************************************
```

```
      SUBROUTINE SHIFT(X,LS,NS)
      DIMENSION X(LS)
      DO 200 J = 1,NS
      Y = X(1)
      DO 100 K = 2,LS
100   X(K-1) = X(K)
200   X(LS) = Y
      RETURN
      END
```

APPENDIX C

PROGRAM SLOPE

```
      Program SLOPE
c**********************************************************
c*   This program was developed as part of an Electrical
c*   Engineering Thesis by Theodore J Moody, entitled,
c*   "Instrumenting an Explosive Test Arena," at the
c*   University of Utah, May 1982.
c**********************************************************
c*      This program reads data from a file and converts
c*      the data to a units of pressure.  It reads the
c*      calibration information at the beginning of the
c*      data, asks the operator what pressure this repre-
c*      sents, then computes a slope and intercept, which
c*      is applied to each data point.  Also inverts the
c*      data.
c***********************************************************
$control nolist
$control file = 25-35
      integer rfln,wfln
      display 'input file number to work on'
      accept ifln
      display 'number of points in top step'
      accept nt
      display 'starting point for top step'
      accept nts
      display 'number of points in zero'
      accept nz
      display 'starting point for ZERO'
      accept nzs
c***********************************************************
c*   Reads TOP STEP information and averages it
c***********************************************************
      do 100 j = 1,(nts-1)
 100  read(ifln,*)x
      sum = 0.0
      k = 0
      do 200 j = nts,(nts+nt-1)
      read(ifln,*,end=300)x
      sum = sum - x
      k = k + 1
 200  continue
 300  x2 = sum/k
      rewind ifln
      sum = 0.0
      k = 0
c***********************************************************
c*   Reads ZERO information and averages it
c***********************************************************
      do 400 j = 1,(nzs-1)
 400  read(ifln,*)x
      do 500 j = nzs,(nzs+nz-1)
      read(ifln,*,end=600)x
      sum = sum - x
```

```
      k = k + 1
 500  continue
 600  x1 = sum / k
      display 'TOP-STEP represents what pressure'
      accept y2
c*****************************************************
c*   Computes Slope and Intercept (xicp) of the data
c*****************************************************
      slope = y2/(x2-x1)
      xicp = -x1 * slope
      display 'Slope =',slope
      display 'Intercept =',xicp
  30  format(1x,I6,5x,g12.5)
  40  format(1x,g12.5)
c*****************************************************
c*    Applies slope and intercept to file to produce a
c*    data file of the desired length in engineering units
c*****************************************************
      display 'how many points in current file'
      accept i
  50  display 'how many points in finished file'
      accept n
      if(i.le.n)go to 110
      display 'finished file needs to be BIGGER!!!!!'
      go to 50
 110  k = 0
c     display 'input slope'
c     accept slope
c     display 'input intercept'
c     accept xicp
      display 'Input file number of file to read from'
      accept rfln
      display 'Input file number of file to write to'
      accept wfln
c*****************************************************
c*   Applies slope and intercept
c*****************************************************
      do 210 j=1,i
      read(rfln,*,end=310)x
      k = k+1
      x = (-x)*slope + xicp
      write(wfln,40)x
 210  write(6,30)k,x
 310  if(k.ge.n)go to 1000
      do 410 j = (k+1),n
 410  write(wfln,40)0.0
      display
     1 (n-k-1),'zeros were added to file',wfln
      go to 1100
1000  display 'There were no zeros added to the file'
1100  stop
      end
```

APPENDIX D

PROGRAM FILTER

```
      Program FILTER
c*****************************************************
c*   This program was developed as part of an Electrical
c*   Engineering Thesis by Theodore J Moody, entitled,
c*   "Instrumenting an Explosive Test Arena," at the
c*   University of Utah, May 1982.
c*****************************************************
$control nolist
$control file = 25-35
      dimension x(4096),y(4096),z(4096)
      integer f,percent
       pii = 3.141593
c*****************************************************
c*   Operator inputs guess for explosive weight, should
c*   be larger than actual
c*****************************************************
       write(6,10)
  10   format(ix,33h
     1        Input equivalent explosive weight)
       accept wt
       write(6,20)
  20   format(ix,29h
     1        Input distance to ground zero)
       accept range
       r = range
c*********************************
c*   Operator selects the power of two for FFT
c*********************************
 125   write(6,130)
 130   format(ix,24hPower of 2 for the FFT =)
       read(5,*)i2p
 140   format(I5)
       n = 2**i2p
       if(n.lt.4097)go to 147
       write(6,146)
 146   format(ix,20hPower of 2 too large)
       go to 125
 147   xlam = r/(wt**(1.0/3.0))
c*********************************
c*     The impulse of the peak overpressure is known only
c*     experimentially, therefore, two equations are
c*     needed to decribe the positive impulse;  one for
c*     the range 0.5<lambda<2.o48 (the equation following
c*     label 410) and one for the range 2.048<lambda<1000
c*     (the equation with label 420).
c*                 ximp = Positive impulse
c*     The following calculates the value of the impulse
c*     for the given lambda.
c*********************************
       x1 = 40.0
       y1 = 0.05
       x2 = 2.048
```

```
      y2 = 11.474
      x3 = 1.442
      y3 = 13.16
      x4 = 1.0
      y4 = 20.0
      x1l = alog10(x1)
      y1l = alog10(y1)
      x2l = alog10(x2)
      y2l = alog10(y2)
      x3l = alog10(x3)
      y3l = alog10(y3)
      x4l = alog10(x4)
      y4l = alog10(y4)
      a = (y1l-y2l)/(x1l-x2l)
      b = y1l - a*x1l
      b = 10.0**b
      c = ((y3l-y4l)*(x2l-x4l)-(x3l-x4l)*(y2l-y4l))/
     1      (((x3l*x3l-x4l*x4l)*(x2l-x4l))-((x3l-x4l)*
     2      (x2l*x2l-x4l*x4l)))
      d = (y2l-y4l-c*(x2l*x2l-x4l*x4l))/(x2l-x4l)
      e = (y4l-(c*x4l*x4l)-d*x4l)
 410  if(xlam.ge.2.048)go to 420
c*****************************************************
c*    Calculates impulse if in parabolic portion
c*****************************************************
      f = alog10(xlam)
      g = (c*f*f)+(d*f)+e
      ximp = range*(10.0**g)
c*****************************************************
c*    Calculates impulse if in linear portion
c*****************************************************
      go to 430
 420  ximp = range*b*((xlam)**a)
 430  continue
c*****************************************************
c*   The following equations are from an article by
c*   L. Giglio-Tos and T.E. Linnenbrink, "Air Blast
c*   Pressure Measurement Systems and Techniques",
c*   MINUTES, 15th DODESB Seminar, September 1973,
c*   p. 1400.  Although the equations in the reference
c*   have considerable overlap, Lambda = 71.725155 was
c*   choosen as the change over point because this is
c*   the point where the two equations are equal (to
c*   9 decimals).
c*   The first equation calculates the peak overpressure
c*   (pm) in the range  0.5<pm<71.725155
c*****************************************************
      if(xlam.gt.71.725155)go to 440
      xlnpm = 7.0452041-1.6277561*(alog(xlam))-0.27399088*
     1        ((alog(xlam))**2)
     2        -0.065973136*((alog(xlam))**3)+0.0065412563*
     3        ((alog(xlam))**4)
```

```
     4          +0.048236359*((alog(xlam))**5)-0.020072553*
     5          ((alog(xlam))**6)
     6          +0.0030190449*((alog(xlam))**7)-0.00015984026*
     7          ((alog(xlam))**8)
        pm = exp(xlnpm)
        go to 450
c*****************************************************
c*    Calculates peak overpressure (pm) in the range
c*             71.725155<pm<1000.0
c*****************************************************
 440    pm = 226.61762/((xlam)**(1.4065913))
c*****************************************************
c*     Calculates the time of the positive phase of the
c*     blast wave (xto) from an analytical integral
c*     solution of the ideal blast wave.
c*****************************************************
 450    xto = 0.001*ximp*2.718281828/pm
c*****************************************************
c*   Operator inputs length of ideal blast wave, should
c*   match length of actual blast wave
c*****************************************************
        display 'number of points in ideal blast wave '
        accept len
c*****************************************************
c*   Operator inputs the sample interval of the actual
c*   data, this correlates the ideal and actual data.
c*****************************************************
        display 'input time per point '
        accept tinc
        t = 0.0
c*****************************************************
c*   Operator chooses the desired % of peak overpressure
c*   This allows him to match the low-pass filter cutoff
c*   used on the analog data.
c*****************************************************
        display'Input desired % of peak (95-100)'
        accept percent
        if(percent eq.100)go to 149
        if(percent.eq.99)a=410.87*pii/xto
        if(percent.eq.98)a=178.58*pii/xto
        if(percent.eq.97)a=108.273*pii/xto
        if(percent.eq.96)a=75.339*pii/xto
        if(percent.eq.95)a=56.5632*pii/xto
        ato = a*xto/(a*xto-1.0)
c*****************************************************
c*   Calculates and files P(t) if 95-99% is chosen
c*****************************************************
        do 500 j=1,len
        b= -t/xto
        c= exp(-a*t)
        d=exp(b)
        x(j) = (ato*((1.0+b)*d-c)+(d-c)*(ato/(a*xto-1.0)))*pm
```

```
      y(j) = 0.0
      t = t+tinc
      write(25)x(j)
 500  continue
      go to 151
c***************************************************************
c*   Calculates and files P(t) if 100% is chosen
c***************************************************************
 149  do 150 j = 1,len
      x(j) = (pm/(exp(t/xto)))*(1-t/xto)
      y(j) =0.0
      t = t + tinc
      write(25)x(j)
 150  continue
c***************************************************************
c*   Zeros remainder of array for FFT
c***************************************************************
 151  do 155 j= (len + 1), n
      x(j) = 0.0
      y(j) = 0.0
 155  write(25)x(j)
      endfile 25
c***************************************************************
c*    Takes FFT of ideal blast wave
c***************************************************************
      call nufft(x,y,i2p,1)
      do 160 f = 1,n
      write(26)x(f)
      write(27)y(f)
 160  continue
      endfile 26
      endfile 27
c************************************
c*    Reads in actual blast wave.
c************************************
      do 170 it = 1,n
      read(28)x(it)
      y(it) = 0.0
 170  continue
c******: *****************************
c*    takes FFT of actual blast wave
c************************************
      call nufft(x,y,i2p,1)
      rewind 26
      rewind 27
c***************************************************************
c*   On a point by point basis, computes magnitude of
c*   actual FFT and then the magnitude of the ideal FFT
c*   and compares the two.  If ideal is larger than the
c*   actual, then the actual value is used.  If actual is
c*   larger than ideal by 2.5%, then the ideal is used as
c*   the frequency domain value of the filtered data.
```

```
c*******************************************************
        do 190 f=1,n
        bmag = sqrt((x(f)**2)+(y(f)**2))
        read(26)pr
        read(27)pi
        pmag = sqrt((pr**2)+(pi**2))
        if(bmag.lt.(1.025*pmag))go to 180
        x(f) = pr
        y(f) = pi
 180    continue
 190    continue
c*******************************************************
c*    Transforms data back to time domain.
c*******************************************************
        call nufft(x,y,i2p,-1)
c*******************************************************
c*   Outputs real and imaginary parts of data to seperate
c*   files, real in file 30 and imaginary in file 31
c*******************************************************
        do 210 it=1,n
        write(30)x(it)
        write(31)y(it)
 210    continue
        endfile 30
        endfile 31
c*******************************************************
c*    Computes min and max of data for plotting purposes.
c*******************************************************
        xmax = 0.0
        xmin = 1000000.0
        ymax = 0.0
        ymin = 1000000.0
        do 220 it= 1,n/2
        if(x(it).gt.xmax)xmax = x(it)
        if(x(it).lt.xmin)xmin = x(it)
        if(y(it).gt.ymax)ymax = y(it)
        if(y(it).lt.ymin)ymin = y(it)
 220    continue
        write(6,230)xmax
 230    format(1x,39h
     1     Maximum of real part of filtered data =,f12.5)
        write(6,240)xmin
 240    format(1x,39h
     1     Minimum of real part of filtered data =,f12.5)
        write(6,250)ymax
 250    format(1x,44h
     1  Maximum of imaginary part of filtered data =,f12.5)
        write(6,260)ymin
 260    format(1x,44h
     1  Minimum of imaginary part of filtered data =,f12.5)
        stop
        end
```

```
C***************************************
C*      This is a subroutine to perform the Fast
C*      Fourier Transform (FFT) of a complex array
C*      where:
C*              XR = Real array
C*              XI = Imaginary Array
C*               M = The order of the FFT (2^M)
C*              IDIRN = The direction of the Transform
C*                       1 = forward
C*                      -1 = reverse
C*      The result returns in XR and XI
C***************************************
        SUBROUTINE NUFFT(XR,XI,M,IDIRN)
        DIMENSION XR(1),XI(1)
        N=2**M
        PI=3.1415927
        DO 20 L=1,M
        LE=2**(M+1-L)
        LE1=LE/2
        UR=1.0
        UI=0.0
        WR=COS(PI/FLOAT(LE1))
        WI=-SIN(PI/FLOAT(LE1))
        DO 20 J=1,LE1
        DO 10 I=J,N,LE
        IP=I+LE1
        TR=XR(I)+XR(IP)
        TI=XI(I)+XI(IP)
        TMR=XR(I)-XR(IP)
        TMI=XI(I)-XI(IP)
        XR(IP)=TMR*UR-TMI*UI
        XI(IP)=TMR*UI+TMI*UR
        XR(I)=TR
10      XI(I)=TI
        TR=UR*WR-UI*WI
        UI=UR*WI+UI*WR
20      UR=TR
        NV2=N/2
        NM1=N-1
        J=1
        DO 30 I=1,NM1
        IF(I .GE. J) GOTO 25
        TR=XR(J)
        TI=XI(J)
        XR(J)=XR(I)
        XI(J)=XI(I)
        XR(I)=TR
        XI(I)=TI
25      K=NV2
26      IF(K .GE. J) GOTO 30
        J=J-K
        K=K/2
```

```
        GOTO 26
30      J=J+K
        IF(IDIRN .EQ. 1) GOTO 77
        DO 99 I=1,N/2
        TTR=XR(I)/N
        TTI=XI(I)/N
        XR(I)=XR(N-I+1)/N
        XI(I)=XI(N-I+1)/N
        XR(N-I+1)=TTR
        XI(N-I+1)=TTI
99      CONTINUE
        TTTR = XR(N)
        TTTI=XI(N)
        DO 777 I=N,2,-1
        XR(I)=XR(I-1)
        XI(I)=XI(I-1)
777     CONTINUE
        XR(1)=TTTR
        XI(1)=TTTI
77      RETURN
        END
C*********************************************************
C*      THIS SUBROUTINE SHIFTS THE ARRAY TO THE RIGHT
C*     N/2 SAMPLES IN A CIRCULAR SHIFT
C*********************************************************
        SUBROUTINE SHIFT(X,LS,NS)
        DIMENSION X(LS)
        DO 200 J = 1,NS
        Y = X(1)
        DO 100 K = 2,LS
100     X(K-1) = X(K)
200     X(LS) = Y
        RETURN
        END
```

APPENDIX E

PROGRAM SMOOTH

```
        Program SMOOTH
c*****************************************************
c*   This program was developed as part of an Electrical
c*   Engineering Thesis by Theodore J Moody, entitled,
c*   "Instrumenting an Explosive Test Arena," at the
c*   University of Utah, May 1982.
c*****************************************************
$control nolist
$control file = 25-35
        integer outfile
        dimension psi(500,2), psit(2,500), x(500,1),
     1            psi2(500,2), thetax(2,1), thetay(2,1),
     2            tm2(2,500),tm1(2,2),y(500,1)
        display 'input file number for Blastwave '
        accept infile
        display 'input file number for filtered wave '
        accept outfile
c*****************************************************
c*  Operator inputs size of sliding window
c*****************************************************
  10    display
     1  ' input number of samples to "average" (EVEN) '
        accept nsam
        nsam2 = nsam/2
        display 'number of samples in data '
        accept ndata
        if(ndata.le.nsam)go to 10
        call ave(infile,outfile,nsam,nsam2,ndata)
        stop
        end
c
c
c*****************************************************
c*   The main part of this program is contained in the
c*   following subroutine to allow for the proper
c*   dimensioning of the arrays.
c*****************************************************
        subroutine ave(infile,outfile,nsam,nsam2,ndata)
        integer outfile
        dimension psi(nsam,2), psit(2,nsam), x(nsam,1),
     1         psi2(nsam,2), thetax(2,1), thetay(2,1),
     2         tm2(2,nsam),tm1(2,2),y(nsam,1)
c*****************************************************
c*   Builds initial psi and X arrays
c*****************************************************
        do 100 j = 1,nsam
        psi(j,1) = float(j)
        psi(j,2) = 1.0
 100    read(infile)x(j,1)
c*****************************************************
c*  computes least square of the first section of data
c*****************************************************
```

```
          call xleast(x,psi,a,b,nsam)
          k = 1
c********************************************************
c*  Outputs the first half window length of smoothed data
c********************************************************
          do 200 j = 1,nsam2
          p = a*psi(j,1) + b
          display k,p
          write(outfile)p
 200      k = k + 1
          k = k - 1
c********************************************************
c*   Starts sliding window over the data one point at a
c*   time computing a new least square for each new data
c*   point and outputs a point representing the center of
c*   the window.
c********************************************************
          do 1000 j=(nsam +1),ndata
          k = k + 1
          call shift(x,nsam,1,1)
          call shift(psi,nsam,2,1)
          psi(nsam,1) = float(k+nsam2)
          read(infile,end=2000)x(nsam,1)
          call xleast(x,psi,a,b,nsam)
          p = a*psi(nsam2,1) + b
          display k,p
          write(outfile)p
1000      continue
2000      do 2100 i = 1,(nsam2)
          k = k + 1
c********************************************************
c*    Computes and outputs the last half window length of
c*    smoothed data using the most recent least square
c*    estimate.
c********************************************************
          p = a*psi(nsam2+i,1) + b
          display k,p
2100      write(outfile)p
          endfile outfile
          return
          end
c
c
c********************************************************
c*   the following subroutine shifts the first column of
c*   the matrix a, no places up
c********************************************************
           subroutine shift(a,m,n,no)
           dimension a(m,n)
           do 100 j=1,(m-no)
           a(j,1) = a(j+no,1)
 100       continue
```

```
          return
          end
c
c
c
c
c*******************************************************
c   This subroutine computes the least square
c  using a standard Least Squares technique.
c*******************************************************
         subroutine xleast(x,psi,a,b,n)
         dimension psi(n,2), psit(2,n), x(n,1), tm1(2,2),
     1              thetax(2,1),thetay(2,1),y(n,1),tm2(2,n)
c*******************************************************
c     The following is the heart of the calculation
c     First a square matrix is formed with
c                     psit x psi = tm1
c     then inverted  and multiplied by   psit   the result
c     is in tm2.  Then tm2 x (the vector X) = thetax  (x
c     component of the solution)
c
c           thetax = (psit x psi)^-1 x psit x X
c
c    For a full explaination see text by G.F. Franklin
c    and J.D. Powell, DIGITAL CONTROL OF DYNAMIC SYSTEMS,
c    (Addison-Wesley Publishing Co., Massachusetts,1981),
c    pp. 216-220.
c*******************************************************
         call xt(psi,psit,n,2)
         call xm(psit,psi,tm1,2,n,2,1.0)
         call xinvert(2,tm1,ierror)
         call xm(tm1,psit,tm2,2,2,n,1.0)
         call xm(tm2,x,thetax,2,n,1,1.0)
         a = thetax(1,1)
         b = thetax(2,1)
         return
         end
c*******************************************************
c
c   TRANSPOSES A MATRIX
c*******************************************************
         Subroutine xt(a,b,m,n)
         dimension a(m,n),b(n,m)
         do 100 i=1,n
            do 100 j = 1,m
               b(i,j) = a(j,i)
 100     continue
         return
         end
c
c
c
```

```
c*******************************************************************
c
c     MATRIX MULTIPLY
C
C*******************************************************************
c
        Subroutine xm(a,b,c,ma,na,nb,scaler)
        dimension a(ma,na),b(na,nb),c(ma,nb)
        do 200 i = 1,nb
           do 200 j = 1,ma
              c(j,i) = 0.0
              do 100 k = 1,na
                 c(j,i) = c(j,i) +a(j,k)*b(k,i)
 100          continue
              c(j,i) = scaler*c(j,i)
 200    continue
        return
        end
c
c*******************************************************************
c*   The following exits the program if the matrix being
c*   inverted is singular.
c*******************************************************************
        Subroutine exitinverse
        write(6,100)
 100    format(1x,31hMatrix is singular, check input)
        write(6,200)
 200    format(1x,12hEXIT PROGRAM)
        stop
        end
c
c*******************************************************************
c*     COMPUTES THE INVERSE OF A MATRIX
c*******************************************************************
        Subroutine xinvert(n,a,ierror)
        dimension a(n,n)
        if(n.gt.2)go to 1000
        temp=a(2,2)
        a(2,2) = a(1,1)
        a(1,1) = temp
        a(1,2) = -a(1,2)
        a(2,1) = -a(2,1)
        temp = a(1,1)*a(2,2) - a(1,2)*a(2,1)
        if(abs(temp).lt.1E-7)call exitinverse
        do 100 i =1,2
        do 100 j =1,2
100     a(i,j) = a(i,j)/temp
        go to 3000
c*******************************************************************
c*   HP3000/33 intrinsic inversion routine
c*******************************************************************
1000    call invert(n,a(1,1),ierror)
```

```
      display ierror
      if(ierror.lt.0.5)call exitinverse
3000  return
      end
```

APPENDIX F

PRINTOUT OF RANGE-BANDWIDTH PRODUCTS

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	144074.	.900000	3.47136	90234.8	.900000
.539511	152819.	.900000	3.60579	88711.9	.899999
.560402	161465.	.900000	3.74542	87199.6	.900000
.582103	169948.	.900000	3.89045	85703.0	.899999
.604644	178200.	.899999	4.04111	84226.8	.900000
.628058	186154.	.900000	4.19759	82775.7	.899999
.652379	193742.	.899999	4.36014	81353.8	.900000
.677641	200894.	.900000	4.52898	79965.0	.899999
.703882	207544.	.900000	4.70436	78612.7	.900000
.731139	213626.	.900000	4.88653	77300.5	.900000
.759451	219078.	.900000	5.07575	76030.9	.900000
.788860	223841.	.899999	5.27230	74806.9	.899999
.819408	227863.	.900000	5.47646	73630.8	.899999
.851138	231095.	.900000	5.68853	72504.6	.900000
.884097	233501.	.900000	5.90881	71430.3	.899999
.918333	235048.	.900000	6.13762	70409.5	.899999
.953894	235713.	.900000	6.37529	69443.5	.899999
.990832	235486.	.900000	6.62217	68533.8	.899999
1.02920	234362.	.899999	6.87860	67681.2	.900000
1.06905	232350.	.900000	7.14497	66886.8	.900000
1.11045	229469.	.899999	7.42164	66151.2	.899999
1.15345	225745.	.899999	7.70904	65475.3	.900000
1.19812	221218.	.900000	8.00756	64859.4	.899999
1.24451	215935.	.899999	8.31764	64304.1	.900000
1.29271	209951.	.900000	8.63973	63809.7	.899999
1.34277	203331.	.899999	8.97429	63376.6	.899999
1.39476	196142.	.899999	9.32181	63005.0	.900000
1.44877	188461.	.900000	9.68279	62695.2	.900000
1.50487	180363.	.900000	10.0577	62447.5	.900000
1.56315	171931.	.899999	10.4472	62261.8	.899999
1.62368	163246.	.900000	10.8518	62138.6	.899999
1.68655	154387.	.899999	11.2720	62077.9	.900000
1.75186	145433.	.899999	11.7085	62079.9	.900000
1.81970	136460.	.900000	12.1619	62145.0	.900000
1.89017	127540.	.899999	12.6328	62273.0	.900000
1.96336	118738.	.900000	13.1220	62464.3	.899999
2.03939	110115.	.899999	13.6301	62719.3	.900000
2.11836	108255.	.899999	14.1579	63038.1	.900000
2.20039	107153.	.900000	14.7062	63420.7	.899999
2.28560	105979.	.899999	15.2757	63867.6	.900000
2.37411	104741.	.899999	15.8672	64379.0	.899999
2.46604	103445.	.899999	16.4816	64955.1	.899999
2.56153	102097.	.899999	17.1199	65596.1	.900000
2.66073	100704.	.900000	17.7828	66302.3	.899999
2.76376	99272.5	.899999	18.4714	67074.0	.900000
2.87078	97808.7	.899999	19.1867	67911.2	.900000
2.98195	96319.4	.899999	19.9297	68814.0	.900000
3.09742	94811.1	.900000	20.7014	69782.8	.900000
3.21736	93290.2	.900000	21.5031	70817.0	.900000
3.34195	91762.6	.900000	22.3357	71917.1	.900000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	73083.0	.899999	155.060	183820.	.899999
24.0991	74314.4	.900000	161.065	186794.	.899999
25.0323	75610.7	.899999	167.302	189816.	.900000
26.0016	76972.3	.900000	173.780	192887.	.900000
27.0085	78397.8	.899999	180.510	196007.	.900000
28.0544	79886.6	.899999	187.500	199178.	.899999
29.1407	81438.8	.899999	194.760	202400.	.900000
30.2692	83052.5	.900000	202.302	205675.	.900000
31.4413	84728.2	.899999	210.136	209002.	.899999
32.6588	86462.5	.899999	218.273	212383.	.900000
33.9235	88255.5	.900000	226.725	215819.	.899999
35.2371	90106.6	.899999	235.505	219311.	.899999
36.6016	92012.8	.899999	244.625	222859.	.900000
38.0190	93971.5	.899999	254.097	226464.	.900000
39.4912	95982.4	.899999	263.937	230128.	.899999
41.0205	98044.3	.900000	274.158	233851.	.899999
42.6089	100153.	.900000	284.774	237634.	.900000
44.2589	102306.	.900000	295.802	241479.	.899999
45.9728	104505.	.899999	307.256	245385.	.899999
47.7530	106744.	.900000	319.154	249355.	.900000
49.6022	109022.	.899999	331.513	253389.	.900000
51.5229	111336.	.900000	344.350	257489.	.899999
53.5181	113685.	.899999	357.685	261654.	.899999
55.5905	116064.	.899999	371.535	265887.	.899999
57.7431	118480.	.900000	385.923	270188.	.900000
59.9791	120915.	.900000	400.867	274559.	.899999
62.3018	123382.	.899999	416.390	279001.	.900000
64.7144	125869.	.900000	432.514	283515.	.900000
67.2203	128387.	.899999	449.262	288102.	.900000
69.8233	130920.	.899999	466.659	292762.	.899999
72.5271	133351.	.899999	484.731	297499.	.900000
75.3357	135509.	.899999	503.501	302311.	.899999
78.2529	137701.	.900000	522.998	307202.	.900000
81.2831	139929.	.900000	543.250	312172.	.900000
84.4307	142193.	.900000	564.287	317222.	.899999
87.7002	144493.	.900000	586.138	322354.	.900000
91.0963	146831.	.900000	608.835	327569.	.900000
94.6238	149206.	.899999	632.412	332869.	.899999
98.2880	151620.	.899999	656.902	338254.	.899999
102.094	154073.	.900000	682.339	343726.	.900000
106.048	156565.	.900000	708.761	349287.	.899999
110.154	159098.	.900000	736.208	354938.	.900000
114.420	161672.	.900000	764.717	360681.	.900000
118.850	164287.	.900000	794.330	366515.	.900000
123.453	166945.	.899999	825.089	372445.	.900000
128.233	169646.	.900000	857.039	378470.	.900000
133.199	172391.	.899999	890.227	384593.	.899999
138.357	175180.	.900000	924.699	390816.	.899999
143.714	178014.	.900000	960.508	397137.	.899999
149.280	180894.	.900000	997.702	403562.	.900000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	365462.	.950000	3.47136	228893.	.950000
.539511	387647.	.950000	3.60579	225030.	.950000
.560402	409579.	.950000	3.74542	221194.	.950000
.582103	431095.	.950000	3.89045	217397.	.950000
.604644	452029.	.950000	4.04111	213653.	.950000
.628058	472205.	.950000	4.19759	209972.	.950000
.652379	491452.	.950000	4.36014	206365.	.950000
.677641	509596.	.950000	4.52898	202842.	.950000
.703882	526465.	.950000	4.70436	199412.	.950000
.731139	541892.	.950000	4.88653	196083.	.950000
.759451	555721.	.950000	5.07575	192863.	.950000
.788860	567803.	.950000	5.27230	189758.	.950000
.819408	578005.	.950000	5.47646	186775.	.950000
.851138	586205.	.950000	5.68853	183912.	.950000
.884097	592307.	.950000	5.90881	181193.	.950000
.918333	596231.	.950000	6.13762	178603.	.950000
.953894	597919.	.950000	6.37529	176153.	.950000
.990832	597343.	.950000	6.62217	173845.	.950000
1.02920	594492.	.950000	6.87860	171683.	950000
1.06905	589388.	.950000	7.14497	169668.	950000
1.11045	582079.	.950000	7.42164	167802.	.950000
1.15345	572634.	.950000	7.70904	166087.	.950000
1.19812	561149.	.950000	8.00756	164525.	.950000
1.24451	547748.	.950000	8.31764	163116.	.950000
1.29271	532570.	.950000	8.63973	161862.	.950000
1.34277	515776.	.950000	8.97429	160764.	.950000
1.39476	497541.	.950000	9.32181	159821.	.950000
1.44877	478056.	.950000	9.68279	159035.	.950000
1.50487	457516.	.950000	10.0577	158407.	.950000
1.56315	436128.	.950000	10.4472	157936.	.950000
1.62368	414096.	.950000	10.8518	157623.	.950000
1.68655	391623.	.950000	11.2720	157469.	.950000
1.75186	368912.	.950000	11.7085	157474.	.950000
1.81970	346150.	.950000	12.1619	157639.	.950000
1.89017	323522.	.950000	12.6328	157964.	.950000
1.96336	301195.	.950000	13.1220	158449.	.950000
2.03939	279321.	.950000	13.6301	159096.	.950000
2.11836	274604.	.950000	14.1579	159905.	.950000
2.20039	271807.	.950000	14.7062	160875.	.950000
2.28560	268831.	.950000	15.2757	162009.	.950000
2.37411	265691.	.950000	15.8672	163306.	.950000
2.46604	262403.	.950000	16.4816	164767.	.950000
2.56153	258984.	.950000	17.1199	166393.	.950000
2.66073	255450.	.950000	17.7828	168185.	.950000
2.76376	251818.	.950000	18.4714	170143.	.950000
2.87078	248105.	.950000	19.1867	172266.	.950000
2.98195	244327.	.950000	19.9297	174556.	.950000
3.09742	240501.	.950000	20.7014	177014.	.950000
3.21736	236643.	.950000	21.5031	179637.	.950000
3.34195	232768.	.950000	22.3357	182428.	.950000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	185385.	.950000	155.060	466284.	.950000
24.0991	188509.	.950000	161.065	473828.	.950000
25.0323	191797.	.950000	167.302	481494.	.950000
26.0016	195251.	.950000	173.780	489283.	.950000
27.0085	198867.	.950000	180.510	497199.	.950000
28.0544	202643.	.950000	187.500	505243.	.950000
29.1407	206581.	.950000	194.760	513416.	.950000
30.2692	210674.	.950000	202.302	521722.	.950000
31.4413	214925.	.950000	210.136	530163.	.950000
32.6588	219324.	.950000	218.273	538739.	.950000
33.9235	223872.	.950000	226.725	547455.	.950000
35.2371	228568.	.950000	235.505	556313.	.950000
36.6016	233403.	.950000	244.625	565311.	.950000
38.0190	238372.	.950000	254.097	574457.	.950000
39.4912	243473.	.950000	263.937	583751.	.950000
41.0205	248703.	.950000	274.158	593195.	.950000
42.6089	254051.	.950000	284.774	602792.	.950000
44.2589	259513.	.950000	295.802	612544.	.950000
45.9728	265092.	.950000	307.256	622452.	.950000
47.7530	270770.	.950000	319.154	632523.	.950000
49.6022	276548.	.950000	331.513	642756.	.950000
51.5229	282420.	.950000	344.350	653155.	.950000
53.5181	288377.	.950000	357.685	663721.	.950000
55.5905	294413.	.950000	371.535	674459.	.950000
57.7431	300541.	.950000	385.923	685370.	.950000
59.9791	306719.	.950000	400.867	696457.	.950000
62.3018	312976.	.950000	416.390	707725.	.950000
64.7144	319283.	.950000	432.514	719175.	.950000
67.2203	325672.	.950000	449.262	730810.	.950000
69.8233	332097.	.950000	466.659	742632.	.950000
72.5271	338264.	.950000	484.731	754646.	.950000
75.3357	343737.	.950000	503.501	766853.	.950000
78.2529	349298.	.950000	522.998	779261.	.950000
81.2831	354949.	.950000	543.250	791867.	.950000
84.4307	360691.	.950000	564.287	804677.	.950000
87.7002	366527.	.950000	586.138	817696.	.950000
91.0963	372456.	.950000	608.835	830923.	.950000
94.6238	378481.	.950000	632.412	844367.	.950000
98.2880	384605.	.950000	656.902	858029.	.950000
102.094	390826.	.950000	682.339	871909.	.950000
106.048	397150.	.950000	708.761	886015.	.950000
110.154	403575.	.950000	736.208	900349.	.950000
114.420	410104.	.950000	764.717	914916.	.950000
118.850	416737.	.950000	794.330	929716	.950000
123.453	423480.	.950000	825.089	944759.	.950000
128.233	430331.	.950000	857.039	960041.	.950000
133.199	437293.	.950000	890.227	975573.	.950000
138.357	444367.	.950000	924.699	991358.	.950000
143.714	451556.	.950000	960.508	.100739E+07	.950000
149.280	458862.	.950000	997.702	.102369E+07	.950000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	486775.	.960000	3.47136	304872.	.960000
.539511	516324.	.960001	3.60579	299727.	.960000
.560402	545536.	.960001	3.74542	294618.	.960000
.582103	574195.	.960000	3.89045	289561.	.960000
.604644	602077.	.960000	4.04111	284574.	.960000
.628058	628951.	.960000	4.19759	279671.	.960001
.652379	654587.	.960000	4.36014	274867.	.960001
.677641	678753.	.960000	4.52898	270174.	.960000
.703882	701221.	.960000	4.70436	265606.	.960001
.731139	721770.	.960000	4.88653	261172.	.960000
.759451	740189.	.960000	5.07575	256883.	.960000
.788860	756281.	.960000	5.27230	252747.	.960001
.819408	769870.	.960000	5.47646	248773.	.960000
.851138	780792.	.960000	5.68853	244968.	.960001
.884097	788920.	.960000	5.90881	241339.	.960000
.918333	794147.	.960000	6.13762	237890.	.960001
.953894	796395.	.960000	6.37529	234626.	.960001
.990832	795627.	.960000	6.62217	231552.	.960000
1.02920	791830.	.960000	6.87860	228672.	.960001
1.06905	785032.	.960000	7.14497	225988.	.960000
1.11045	775296.	.960000	7.42164	223502.	.960000
1.15345	762716	.960000	7.70904	221219.	.960000
1.19812	747418.	.960001	8.00756	219138.	.960000
1.24451	729570.	.960000	8.31764	217262.	.960001
1.29271	709353.	.960001	8.63973	215591.	.960000
1.34277	686985.	.960000	8 97429	214128.	.960000
1.39476	662697.	.960001	9 32181	212872.	.960000
1.44877	636744.	.960001	9.68279	211826.	.960000
1.50487	609385.	.960000	10.0577	210989.	.960000
1.56315	580898.	.960000	10.4472	210361.	.960001
1.62368	551552.	.960000	10.8518	209945.	.960001
1.68655	521620.	.960000	11.2720	209740.	.960000
1.75186	491369.	.960000	11.7085	209747.	.960001
1.81970	461053.	.960000	12.1619	209967.	.960000
1.89017	430913.	.960000	12.6328	210399.	.960000
1.96336	401175.	.960000	13.1220	211046.	.960000
2.03939	372040.	.960001	13.6301	211907.	.960000
2.11836	365757.	.960000	14.1579	212984.	.960000
2.20039	362032.	.960000	14.7062	214277.	.960000
2.28560	358068.	.960000	15.2757	215787.	.960000
2.37411	353885.	.960000	15.8672	217515.	.960000
2.46604	349507.	.960000	16.4816	219461.	.960000
2.56153	344952.	.960000	17.1199	221627.	.960000
2.66073	340245.	.960000	17.7828	224013.	.960000
2.76376	335408.	.960000	18.4714	226620.	.960000
2.87078	330462.	.960001	19.1867	229449.	.960000
2.98195	325430.	.960000	19.9297	232499.	.960000
3.09742	320334.	.960000	20.7014	235772.	.960000
3.21736	315196.	.960000	21.5031	239266.	.960000
3.34195	310035.	.960000	22.3357	242983.	.960000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	246922.	.960000	155.060	621065.	.960000
24.0991	251083.	.960000	161.065	631112.	.960000
25.0323	255463.	.960000	167.302	641323.	.960000
26.0016	260063.	.960001	173.780	651698.	.960000
27.0085	264879.	.960001	180.510	662241.	.960001
28.0544	269909.	.960000	187.500	672955.	.960000
29.1407	275154.	.960000	194.760	683841.	.960001
30.2692	280606.	.960000	202.302	694904.	.960000
31.4413	286268.	.960000	210.136	706147.	.960000
32.6588	292127.	.960000	218.273	717570.	.960000
33.9235	298185.	.960000	226.725	729179.	.960000
35.2371	304439.	.960001	235.505	740977.	.960000
36.6016	310880.	.960000	244.625	752963.	.960000
38.0190	317498.	.960000	254.097	765144.	.960001
39.4912	324292.	.960000	263.937	777523.	.960000
41.0205	331258.	.960000	274.158	790102.	.960001
42.6089	338382.	.960000	284.774	802885.	.960000
44.2589	345657.	.960000	295.802	815874.	.960001
45.9728	353087.	.960000	307.256	829072.	.960001
47.7530	360651.	.960001	319.154	842485.	.960001
49.6022	368347.	.960000	331.513	856114.	.960000
51.5229	376168.	.960001	344.350	869966.	.960000
53.5181	384102.	.960000	357.685	884039.	.960001
55.5905	392142.	.960000	371.535	898342.	.960000
57.7431	400303.	.960000	385.923	912874.	.960001
59.9791	408532.	.960000	400.867	927642.	.960001
62.3018	416866.	.960001	416.390	942650.	.960000
64.7144	425267.	.960000	432.514	957901.	.960000
67.2203	433777.	.960000	449.262	973398.	.960001
69.8233	442335.	.960000	466.659	989144.	.960001
72.5271	450549.	.960000	484.731	.100515E+07	.960000
75.3357	457839.	.960001	503.501	.102141E+07	.960000
78.2529	465245.	.960001	522.998	.103793E+07	.960000
81.2831	472772.	.960000	543.250	.105472E+07	.960001
84.4307	480421.	.960000	564.287	.107179E+07	.960000
87.7002	488193.	.960000	586.138	.108912E+07	.960000
91.0963	496090.	.960000	608.835	.110674E+07	.960000
94.6238	504115.	.960000	632.412	.112465E+07	.960000
98.2880	512272.	.960001	656.902	.114285E+07	.960000
102.094	520558.	.960001	682.339	.116133E+07	.960001
106.048	528981.	.960000	708.761	.118012E+07	.960000
110.154	537539.	.960000	736.208	.119921E+07	.960000
114.420	546235.	.960000	764.717	.121862E+07	.960001
118.850	555071.	.960000	794.330	.123833E+07	.960000
123.453	564052.	.960000	825.089	.125837E+07	.960000
128.233	573177.	.960000	857.039	.127872E+07	.960001
133.199	582449.	.960000	890.227	.129941E+07	.960000
138.357	591872.	.960001	924.699	.132043E+07	.960000
143.714	601447.	.960000	960.508	.134179E+07	.960000
149.280	611179.	.960000	997.702	.136350E+07	.960000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	699566.	.970000	3.47136	438146.	.970000
.539511	742032.	.970000	3.60579	430751.	.970000
.560402	784014.	.970000	3.74542	423408.	.970000
.582103	825201.	.970000	3.89045	416141.	.970000
.604644	865271.	.970000	4.04111	408973.	.970000
.628058	903893.	.970000	4.19759	401927.	.970000
.652379	940736.	.970000	4.36014	395023.	.970000
.677641	975466.	.970000	4.52898	388279.	.970000
.703882	.100776E+07	.970000	4.70436	381713.	.970000
.731139	.103729E+07	.970000	4.88653	375342.	.970000
.759451	.106376E+07	.970000	5.07575	369177.	.970000
.788860	.108688E+07	.970000	5.27230	363234.	.970000
.819408	.110641E+07	.970000	5.47646	357523.	.970000
.851138	.112211E+07	.970000	5.68853	352055.	.970000
.884097	.113379E+07	.970000	5.90881	346838.	.970000
.918333	.114130E+07	.970000	6.13762	341882.	.970000
.953894	.114453E+07	.970000	6.37529	337191.	.970000
.990832	.114343E+07	.970000	6.62217	332774.	.970000
1.02920	.113797E+07	.970000	6.87860	328634.	.970000
1.06905	.112820E+07	.970000	7.14497	324777.	.970000
1.11045	.111421E+07	.970000	7.42164	321205.	.970000
1.15345	.109613E+07	.970000	7.70904	317923.	.970000
1.19812	.107415E+07	.970000	8.00756	314932.	.970000
1.24451	.104850E+07	.970000	8.31764	312236.	.970000
1.29271	.101944E+07	.970000	8.63973	309836.	.970000
1.34277	987296.	.970000	8.97429	307733.	.970000
1.39476	952391.	.970000	9.32181	305928.	.970000
1.44877	915093.	.970000	9.68279	304424.	.970000
1.50487	875775.	.970000	10.0577	303221.	.970000
1.56315	834833.	.970000	10.4472	302320.	.970000
1.62368	792660.	.970000	10.8518	301721.	.970000
1.68655	749643.	.970000	11.2720	301427.	.970000
1.75186	706169.	.970000	11.7085	301436.	.970000
1.81970	662599.	.970000	12.1619	301752.	.970000
1.89017	619284.	.970000	12.6328	302374.	.970000
1.96336	576546.	.970000	13.1220	303303.	.970000
2.03939	534675.	.970000	13.6301	304541.	.970000
2.11836	525645.	.970000	14.1579	306089.	.970000
2.20039	520292.	.970000	14.7062	307947.	.970000
2.28560	514595.	.970000	15.2757	310117.	.970000
2.37411	508584.	.970000	15.8672	312600.	.970000
2.46604	502291.	.970000	16.4816	315397.	.970000
2.56153	495746.	.970000	17.1199	318509.	.970000
2.66073	488981.	.970000	17.7828	321939.	.970000
2.76376	482029.	.970000	18.4714	325686.	.970000
2.87078	474922.	.970000	19.1867	329751.	.970000
2.98195	467690.	.970000	19.9297	334135.	.970000
3.09742	460366.	.970000	20.7014	338838.	.970000
3.21736	452982.	.970000	21.5031	343860.	.970000
3.34195	445564.	.970000	22.3357	349202.	.970000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	354863.	.970000	155.060	892559.	.970000
24.0991	360842.	.970000	161.065	906999.	.970000
25.0323	367137.	.970000	167.302	921674.	.970000
26.0016	373748.	.970000	173.780	936584.	.970000
27.0085	380670.	.970000	180.510	951736.	.970000
28.0544	387899.	.970000	187.500	967133.	.970000
29.1407	395436.	.970000	194.760	982778.	.970000
30.2692	403271.	.970000	202.302	998677.	.970000
31.4413	411408.	.970000	210.136	.101483E+07	.970000
32.6588	419829.	.970000	218.273	.103125E+07	.970000
33.9235	428535.	.970000	226.725	.104794E+07	.970000
35.2371	437523.	.970000	235.505	.106489E+07	.970000
36.6016	446779.	.970000	244.625	.108212E+07	.970000
38.0190	456290.	.970000	254.097	.109962E+07	.970000
39.4912	466054.	.970000	263.937	.111741E+07	.970000
41.0205	476066.	.970000	274.158	.113549E+07	.970000
42.6089	486303.	.970000	284.774	.115386E+07	.970000
44.2589	496759.	.970000	295.802	.117253E+07	.970000
45.9728	507437.	.970000	307.256	.119150E+07	.970000
47.7530	518307.	.970000	319.154	.121077E+07	.970000
49.6022	529367.	.970000	331.513	.123036E+07	.970000
51.5229	540607.	.970000	344.350	.125027E+07	.970000
53.5181	552010.	.970000	357.685	.127049E+07	.970000
55.5905	563564.	.970000	371.535	.129105E+07	.970000
57.7431	575293.	.970000	385.923	.131193E+07	.970000
59.9791	587119.	.970000	400.867	.133316E+07	.970000
62.3018	599096.	.970000	416.390	.135472E+07	.970000
64.7144	611170.	.970000	432.514	.137664E+07	.970000
67.2203	623400.	.970000	449.262	.139891E+07	.970000
69.8233	635699.	.970000	466.659	.142154E+07	.970000
72.5271	647504.	.970000	484.731	.144454E+07	.970000
75.3357	657980.	.970000	503.501	.146791E+07	.970000
78.2529	668624.	.970000	522.998	.149166E+07	.970000
81.2831	679442.	.970000	543.250	.151579E+07	.970000
84.4307	690434.	.970000	564.287	.154031E+07	.970000
87.7002	701603.	.970000	586.138	.156523E+07	.970000
91.0963	712953.	.970000	608.835	.159055E+07	.970000
94.6238	724486.	.970000	632.412	.161628E+07	.970000
98.2880	736208.	.970000	656.902	.164243E+07	.970000
102.094	748117.	.970000	682.339	.166900E+07	.970000
106.048	760222.	.970000	708.761	.169600E+07	.970000
110.154	772521.	.970000	736.208	.172344E+07	.970000
114.420	785019.	.970000	764.717	.175133E+07	.970000
118.850	797717.	.970000	794.330	.177966E+07	.970000
123.453	810623.	.970000	825.089	.180845E+07	.970000
128.233	823738.	.970000	857.039	.183771E+07	.970000
133.199	837063.	.970000	890.227	.186744E+07	.970000
138.357	850605.	.970000	924.699	.189765E+07	.970000
143.714	864366.	.970000	960.508	.192835E+07	.970000
149.280	878351.	.970000	997.702	.195954E+07	.970000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	.115383E+07	.980000
.539511	.122387E+07	.980000
.560402	.129311E+07	.980000
.582103	.136104E+07	.980000
.604644	.142713E+07	.980000
.628058	.149084E+07	.980000
.652379	.155160E+07	.980000
.677641	.160888E+07	.980000
.703882	.166214E+07	.980000
.731139	.171085E+07	.980000
.759451	.175451E+07	.980000
.788860	.179265E+07	.980000
.819408	.182486E+07	.980000
.851138	.185075E+07	.980000
.884097	.187002E+07	.980000
.918333	.188241E+07	.980000
.953894	.188774E+07	.980000
.990832	.188592E+07	.980000
1.02920	.187692E+07	.980000
1.06905	.186080E+07	.980000
1.11045	.183772E+07	.980000
1.15345	.180791E+07	.980000
1.19812	.177165E+07	.980000
1.24451	.172934E+07	.980000
1.29271	.168142E+07	.980000
1.34277	.162840E+07	.980000
1.39476	.157083E+07	.980000
1.44877	.150931E+07	.980000
1.50487	.144446E+07	.980000
1.56315	.137693E+07	.980000
1.62368	.130737E+07	.980000
1.68655	.123642E+07	.980000
1.75186	.116472E+07	.980000
1.81970	.109286E+07	.980000
1.89017	.102142E+07	.980000
1.96336	950925.	.980000
2.03939	881865.	.980000
2.11836	866973.	.980000
2.20039	858143.	.980000
2.28560	848746.	.980000
2.37411	838833.	.980000
2.46604	828454.	.980000
2.56153	817659.	.980000
2.66073	806500.	.980000
2.76376	795035.	.980000
2.87078	783312.	.980000
2.98195	771385.	.980000
3.09742	759305.	.980000
3.21736	747125.	.980000
3.34195	734891.	.980000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak
3.47136	722655.	.980000
3.60579	710459.	.980000
3.74542	698347.	.980000
3.89045	686362.	.980000
4.04111	674540.	.980000
4.19759	662918.	.980000
4.36014	651531.	.980000
4.52898	640408.	.980000
4.70436	629579.	.980000
4.88653	619069.	.980000
5.07575	608902.	.980000
5.27230	599099.	.980000
5.47646	589680.	.980000
5.68853	580661.	.980000
5.90881	572058.	.980000
6.13762	563882.	.980000
6.37529	556146.	.980000
6.62217	548860.	.980000
6.87860	542032.	.980000
7.14497	535671.	.980000
7.42164	529779.	.980000
7.70904	524366.	.980000
8.00756	519434.	.980000
8.31764	514987.	.980000
8.63973	511027.	.980000
8.97429	507559.	.980000
9.32181	504583.	.980000
9.68279	502102.	.980000
10.0577	500117.	.980000
10.4472	498631.	.980000
10.8518	497644.	.980000
11.2720	497158.	.980000
11.7085	497174.	.980000
12.1619	497695.	.980000
12.6328	498720.	.980000
13.1220	500252.	.980000
13.6301	502295.	.980000
14.1579	504848.	.980000
14.7062	507912.	.980000
15.2757	511491.	.980000
15.8672	515586.	.980000
16.4816	520280.	.980000
17.1199	525333.	.980000
17.7828	530989.	.980000
18.4714	537170.	.980000
19.1867	543874.	.980000
19.9297	551105.	.980000
20.7014	558863.	.980000
21.5031	567146.	.980000
22.3357	575956.	.980000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	585293.	.980000	155.060	.147214E+07	.980000
24.0991	595155.	.980000	161.065	.149596E+07	.980000
25.0323	605537.	.980000	167.302	.152016E+07	.980000
26.0016	616441.	.980000	173.780	.154475E+07	.980000
27.0085	627857.	.980000	180.510	.156974E+07	.980000
28.0544	639780.	.980000	187.500	.159514E+07	.980000
29.1407	652212.	.980000	194.760	.162094E+07	.980000
30.2692	665135.	.980000	202.302	.164717E+07	.980000
31.4413	678555.	.980000	210.136	.167382E+07	.980000
32.6588	692445.	.980000	218.273	.170089E+07	.980000
33.9235	706804.	.980000	226.725	.172841E+07	.980000
35.2371	721629.	.980000	235.505	.175638E+07	.980000
36.6016	736895.	.980000	244.625	.178479E+07	.980000
38.0190	752582.	.980000	254.097	.181366E+07	.980000
39.4912	768686.	.980000	263.937	.184300E+07	.980000
41.0205	785199.	.980000	274.158	.187282E+07	.980000
42.6089	802083.	.980000	284.774	.190312E+07	.980000
44.2589	819329.	.980000	295.802	.193391E+07	.980000
45.9728	836941.	.980000	307.256	.196519E+07	.980000
47.7530	854869.	.980000	319.154	.199699E+07	.980000
49.6022	873111.	.980000	331.513	.202929E+07	.980000
51.5229	891650.	.980000	344.350	.206212E+07	.980000
53.5181	910458.	.980000	357.685	.209548E+07	.980000
55.5905	929514.	.980000	371.535	.212939E+07	.980000
57.7431	948860.	.980000	385.923	.216383E+07	.980000
59.9791	968364.	.980000	400.867	.219884E+07	.980000
62.3018	988119.	.980000	416.390	.223441E+07	.980000
64.7144	.100803E+07	.980000	432.514	.227056E+07	.980000
67.2203	.102820E+07	.980000	449.262	.230730E+07	.980000
69.8233	.104849E+07	.980000	466.659	.234462E+07	.980000
72.5271	.106796E+07	.980000	484.731	.238255E+07	.980000
75.3357	.108524E+07	.980000	503.501	.242109E+07	.980000
78.2529	.110279E+07	.980000	522.998	.246026E+07	.980000
81.2831	.112064E+07	.980000	543.250	.250007E+07	.980000
84.4307	.113877E+07	.980000	564.287	.254051E+07	.980000
87.7002	.115719E+07	.980000	586.138	.258161E+07	.980000
91.0963	.117591E+07	.980000	608.835	.262337E+07	.980000
94.6238	.119493E+07	.980000	632.412	.266582E+07	.980000
98.2880	.121426E+07	.980000	656.902	.270895E+07	.980000
102.094	.123391E+07	.980000	682.339	.275277E+07	.980000
106.048	.125387E+07	.980000	708.761	.279730E+07	.980000
110.154	.127416E+07	.980000	736.208	.284256E+07	.980000
114.420	.129477E+07	.980000	764.717	.288855E+07	.980000
118.850	.131571E+07	.980000	794.330	.293528E+07	.980000
123.453	.133700E+07	.980000	825.089	.298277E+07	.980000
128.233	.135863E+07	.980000	857.039	.303102E+07	.980000
133.199	.138061E+07	.980000	890.227	.308006E+07	.980000
138.357	.140295E+07	.980000	924.699	.312989E+07	.980000
143.714	.142564E+07	.980000	960.508	.318052E+07	.980000
149.280	.144871E+07	.980000	997.702	.323197E+07	.980000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
.519397	.265469E+07	.990000	3.47136	.166266E+07	.990000
.539511	.281583E+07	.990000	3.60579	.163460E+07	.990000
.560402	.297515E+07	.990000	3.74542	.160673E+07	.990000
.582103	.313144E+07	.990000	3.89045	.157915E+07	.990000
.604644	.328349E+07	.990000	4.04111	.155195E+07	.990000
.628058	.343006E+07	.990000	4.19759	.152522E+07	.990000
.652379	.356986E+07	.990000	4.36014	.149902E+07	.990000
.677641	.370166E+07	.990000	4.52898	.147343E+07	.990000
.703882	.382419E+07	.990000	4.70436	.144851E+07	.990000
.731139	.393625E+07	.990000	4.88653	.142433E+07	.990000
.759451	.403671E+07	.990000	5.07575	.140094E+07	.990000
.788860	.412447E+07	.990000	5.27230	.137838E+07	.990000
.819408	.419857E+07	.990000	5.47646	.135671E+07	.990000
.851138	.425814E+07	.990000	5.68853	.133596E+07	.990000
.884097	.430246E+07	.990000	5.90881	.131617E+07	.990000
.918333	.433097E+07	.990000	6.13762	.129736E+07	.990000
.953894	.434323E+07	.990000	6.37529	.127956E+07	.990000
.990832	.433904E+07	.990000	6.62217	.126280E+07	.990000
1.02920	.431834E+07	.990000	6.87860	.124709E+07	.990000
1.06905	.428126E+07	.990000	7.14497	.123245E+07	.990000
1.11045	.422817E+07	.990000	7.42164	.121890E+07	.990000
1.15345	.415956E+07	.990000	7.70904	.120644E+07	.990000
1.19812	.407613E+07	.990000	8.00756	.119509E+07	.990000
1.24451	.397879E+07	.990000	8.31764	.118486E+07	.990000
1.29271	.386854E+07	.990000	8.63973	.117575E+07	.990000
1.34277	.374655E+07	.990000	8.97429	.116777E+07	.990000
1.39476	.361409E+07	.990000	9.32181	.116092E+07	.990000
1.44877	.347256E+07	.990000	9.68279	.115522E+07	.990000
1.50487	.332335E+07	.990000	10.0577	.115065E+07	.990000
1.56315	.316799E+07	.990000	10.4472	.114723E+07	.990000
1.62368	.300795E+07	.990000	10.8518	.114496E+07	.990000
1.68655	.284472E+07	.990000	11.2720	.114384E+07	.990000
1.75186	.267974E+07	.990000	11.7085	.114388E+07	.990000
1.81970	.251440E+07	.990000	12.1619	.114508E+07	.990000
1.89017	.235003E+07	.990001	12.6328	.114744E+07	.990000
1.96336	.218785E+07	.990000	13.1220	.115096E+07	.990001
2.03939	.202896E+07	.990000	13.6301	.115566E+07	.990000
2.11836	.199470E+07	.990000	14.1579	.116153E+07	.990000
2.20039	.197438E+07	.990000	14.7062	.116858E+07	.990000
2.28560	.195276E+07	.990000	15.2757	.117682E+07	.990000
2.37411	.192995E+07	.990000	15.8672	.118624E+07	.990000
2.46604	.190607E+07	.990000	16.4816	.119686E+07	.990000
2.56153	.188124E+07	.990000	17.1199	.120867E+07	.990000
2.66073	.185556E+07	.990000	17.7828	.122168E+07	.990001
2.76376	.182919E+07	.990000	18.4714	.123590E+07	.990001
2.87078	.180221E+07	.990000	19.1867	.125132E+07	.990000
2.98195	.177477E+07	.990000	19.9297	.126796E+07	.990000
3.09742	.174698E+07	.990000	20.7014	.128581E+07	.990000
3.21736	.171896E+07	.990000	21.5031	.130487E+07	.990000
3.34195	.169081E+07	.990000	22.3357	.132514E+07	.990000

Lambda	Range-Bandwidth Product (ft-Hz)	Peak	Lambda	Range-Bandwidth Product (ft-Hz)	Peak
23.2007	.134662E+07	.990000	155.060	.338705E+07	.990000
24.0991	.136931E+07	.990000	161.065	.344184E+07	.990000
25.0323	.139320E+07	.990000	167.302	.349753E+07	.990000
26.0016	.141828E+07	.990000	173.780	.355411E+07	.990000
27.0085	.144455E+07	.990000	180.510	.361161E+07	.990000
28.0544	.147198E+07	.990000	187.500	.367004E+07	.990000
29.1407	.150058E+07	.990000	194.760	.372940E+07	.990000
30.2692	.153032E+07	.990000	202.302	.378974E+07	.990000
31.4413	.156119E+07	.990000	210.136	.385105E+07	.990000
32.6588	.159315E+07	.990000	218.273	.391335E+07	.990000
33.9235	.162619E+07	.990001	226.725	.397666E+07	.990000
35.2371	.166030E+07	.990000	235.505	.404101E+07	.990000
36.6016	.169542E+07	.990000	244.625	.410637E+07	.990000
38.0190	.173151E+07	.990000	254.097	.417280E+07	.990000
39.4912	.176856E+07	.990000	263.937	.424031E+07	.990001
41.0205	.180656E+07	.990000	274.158	.430892E+07	.990000
42.6089	.184540E+07	.990000	284.774	.437863E+07	.990000
44.2589	.188508E+07	.990000	295.802	.444947E+07	.990000
45.9728	.192560E+07	.990000	307.256	.452144E+07	.990000
47.7530	.196685E+07	.990000	319.154	.459459E+07	.990000
49.6022	.200882E+07	.990000	331.513	.466892E+07	.990000
51.5229	.205147E+07	.990000	344.350	.474446E+07	.990000
53.5181	.209475E+07	.990000	357.685	.482121E+07	.990000
55.5905	.213859E+07	.990000	371.535	.489921E+07	.990000
57.7431	.218310E+07	.990000	385.923	.497846E+07	.990000
59.9791	.222798E+07	.990000	400.867	.505900E+07	.990000
62.3018	.227343E+07	.990000	416.390	.514085E+07	.990000
64.7144	.231924E+07	.990000	432.514	.522402E+07	.990000
67.2203	.236565E+07	.990000	449.262	.530854E+07	.990000
69.8233	.241232E+07	.990001	466.659	.539441E+07	.990000
72.5271	.245712E+07	.990000	484.731	.548168E+07	.990000
75.3357	.249688E+07	.990000	503.501	.557035E+07	.990000
78.2529	.253727E+07	.990000	522.998	.566048E+07	.990000
81.2831	.257832E+07	.990000	543.250	.575205E+07	.990000
84.4307	.262003E+07	.990000	564.287	.584510E+07	.990000
87.7002	.266242E+07	.990000	586.138	.593967E+07	.990000
91.0963	.270549E+07	.990000	608.835	.603575E+07	.990000
94.6238	.274925E+07	.990000	632.412	.613341E+07	.990000
98.2880	.279373E+07	.990000	656.902	.623264E+07	.990000
102.094	.283893E+07	.990000	682.339	.633347E+07	.990000
106.048	.288486E+07	.990000	708.761	.643593E+07	.990000
110.154	.293153E+07	.990000	736.208	.654005E+07	.990000
114.420	.297896E+07	.990000	764.717	.664587E+07	.990000
118.850	.302714E+07	.990000	794.330	.675338E+07	.990000
123.453	.307612E+07	.990000	825.089	.686264E+07	.990000
128.233	.312589E+07	.990000	857.039	.697365E+07	.990000
133.199	.317645E+07	.990000	890.227	.708648E+07	.990000
138.357	.322784E+07	.990000	924.699	.720113E+07	.990000
143.714	.328006E+07	.990000	960.508	.731761E+07	.990000
149.280	.333313E+07	.990000	997.702	.743600E+07	.990000

REFERENCES

1. G.F. Kinney, Explosive Shocks in Air, (The MacMillan Company, New York, 1962).

2. L. Giglio-Tos and T.E. Linnenbrink, "Air Blast Pressure Measurement Systems and Techniques," Minutes, 15th Department of Defense Explosive Safety Board Seminar, September 1973.

3. Department of the Air Force Technical Order, TO 11A-1-47, Department of Defense Explosive Hazard Classification Procedures, March 1981.

4. M. Schwartz, Information Transmission, Modulation and Noise, 3rd ed., (McGraw-Hill Book Company, New York, 1980).

5. G. Dahlquist and A. Bjorck, Numerical Methods, translated by N. Anderson, (Prentice-Hall, Inc., New Jersey, 1974).

6. G.F. Franklin and J.D. Powell, Digital Control of Dynamic Systems, (Addison-Wesley Publishing Co., Massachusetts, 1981).

VITA

Name	Theodore James Moody
Birthdate	[redacted]
Birthplace	[redacted]
High School	[redacted]
University	
1968-1971	University of Alaska Anchorage, Alaska
1972-1973	University of North Dakota Grand Forks AFB, ND
1974-1976	University of Wyoming Laramie, Wyoming
Degree	
1976	B.S.E.E. University of Wyoming Laramie, Wyoming
Professional Organizations	Tau Beta Pi, Phi Kappa Phi, Air Force Association
Professional Positions	Chief, Range Instrumention Unit, Hill AFB, Utah, 1978-1980; Instructor, Weber State College, 1979-1980; Aircraft Electrical Component RDT&E Engineer, Hill AFB, Utah, 1977-1978; Navigation and Bombing Tactics Trainer Technician, Grand Forks AFB, North Dakota, 1972-1974; Power Production Technician, Elmendorf AFB, Alaska, 1968-1971; Power Production Technician, Cape Romanzof, Alaska, 1967-1968; Instructor, Power Production, Sheppard AFB, Texas, 1966-1967.